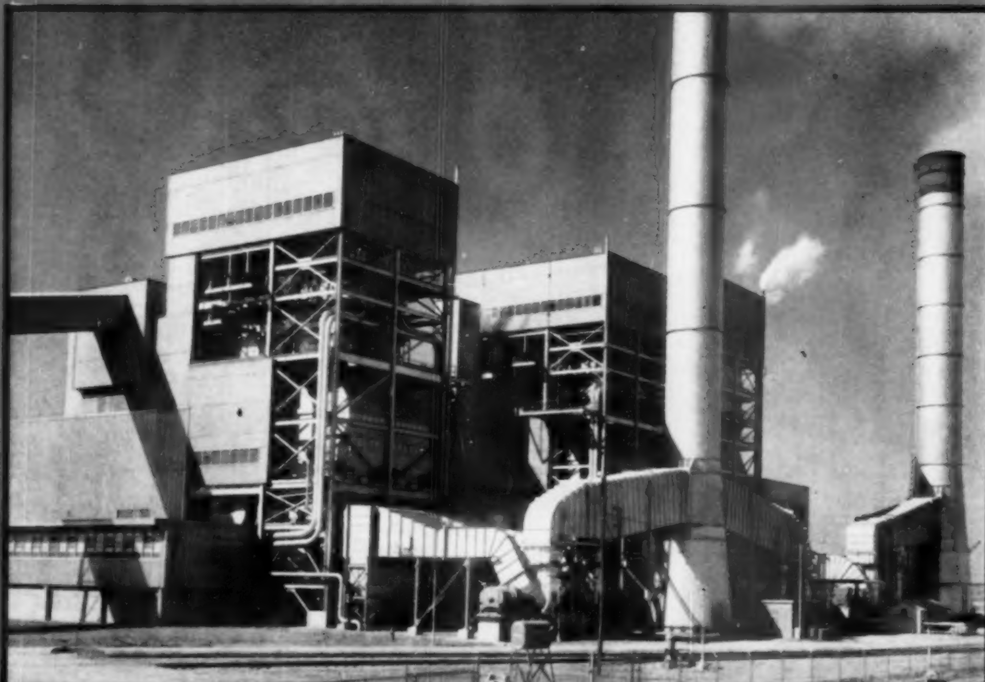
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

December 1955



View of the recently completed Hawthorne Station, Kansas City Power & Light Company

Charging for Steam in Industrial Plants

Accuracy of Laboratory Coal Analyses

Commonwealth Edison's Third Unit at State Line

ASME Annual Meeting Review

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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December 1955

Feature Articles

Editorials

Departments

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BPA

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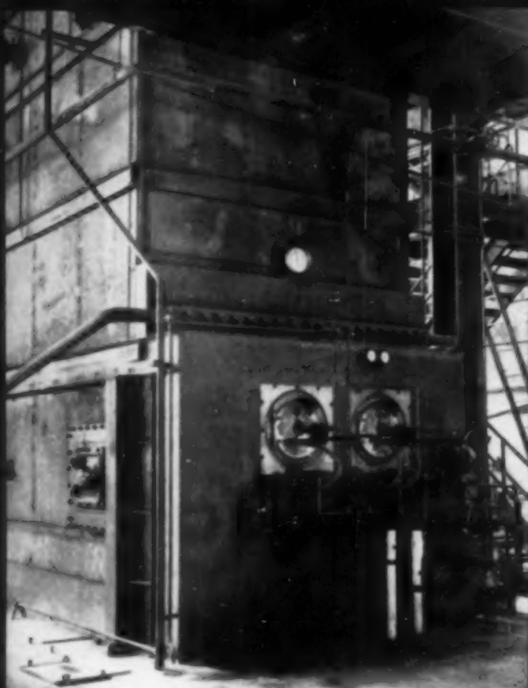
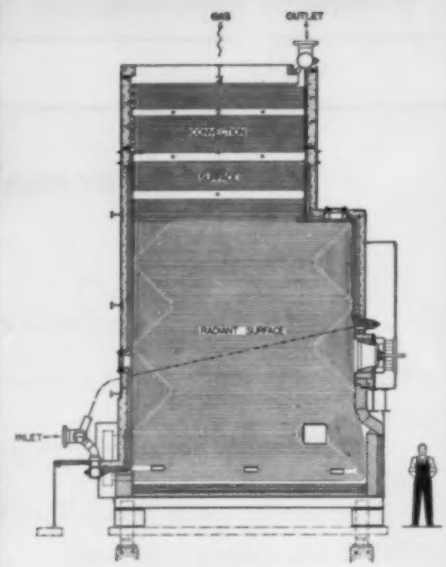
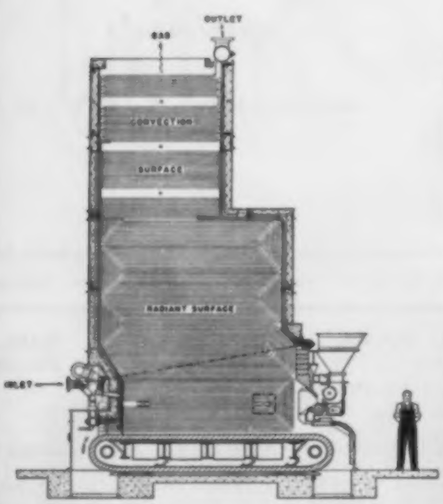
C-E LaMont Controlled Circulation Hot Water Boilers



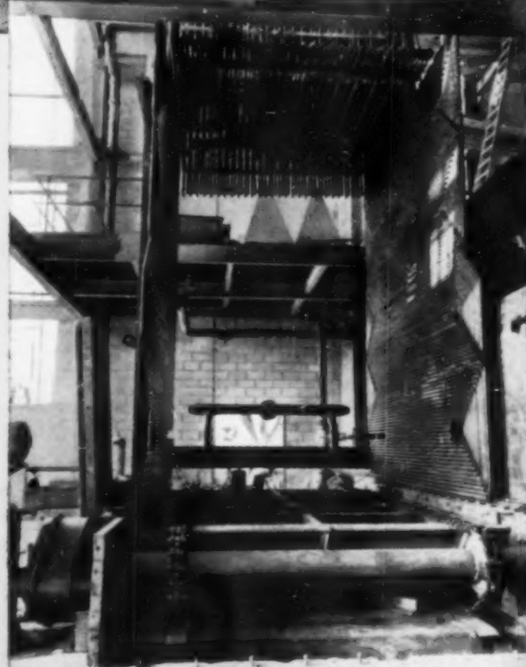
Installation view — oil fired unit.



Typical arrangement — as fired with oil or gas.



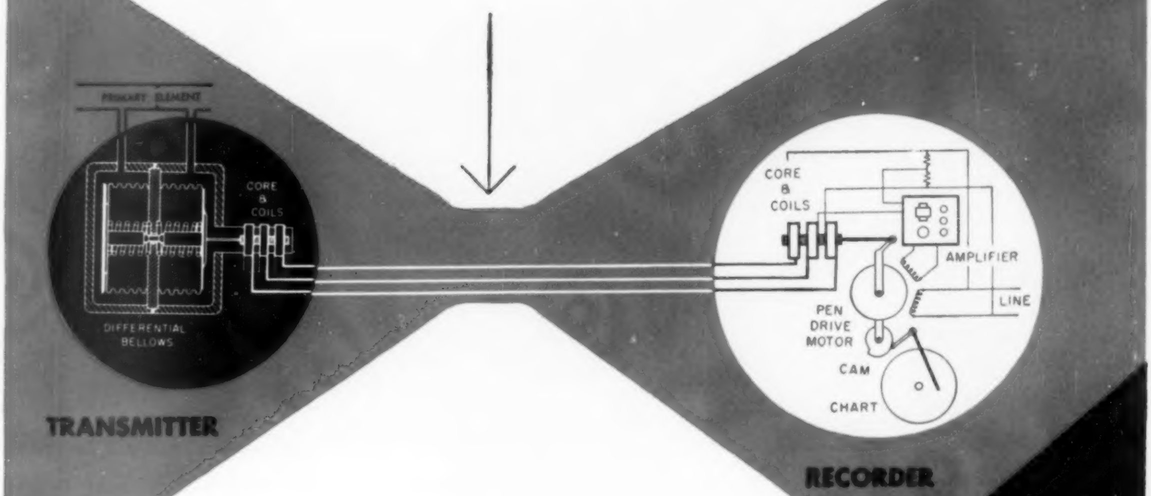
Typical arrangement — as fired with C-E Spreader Stoker.



Erection view — with C-E Spreader Stoker.

new dimensions

IN FLOW METERING



THE HAYS ELECTRONIC FLOW METER

Here is a new Flow Meter—that is really new! These features of the Hays Electronic Flow Meter speak for themselves.

Mercuryless—costly mercury maintenance headaches eliminated—no mercury to lose.

Rupture-proof Bellows—provide positive protection against over-range.

Continuous integration—motor-driven continuous mechanical integrator is extremely accurate even on rapid load changes.

Electronic operation—requires only 4 seconds for full scale pen travel with accuracy of $\frac{1}{4}$% of full scale differential.

Other features include null-balance transmission, powerful motor, easy readability, accuracy unaffected by normal temperature changes. Explosion proof transmitters and wide range meters also available.

For complete information, write for Bulletin 54-1074-222.

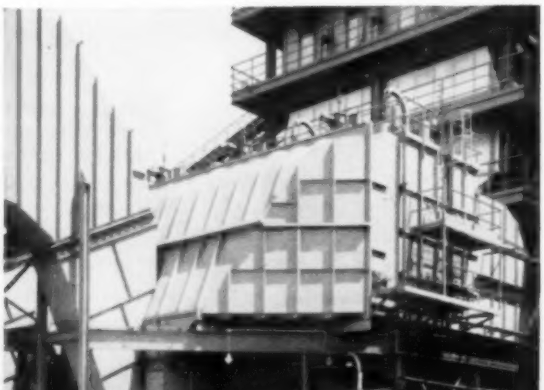
THE **hays** CORPORATION

MICHIGAN CITY 1, INDIANA

Automatic Combustion Control • Veriflow Meters and Verirol • Electronic Oxygen Recorders • CO_2 Recorders Boiler Panels • Gas Analyzers • Combustion Test Sets Draft Gages • Electronic Flowmeters • Miniature Remote Indicators • Electronic Feed Water Controls

Sewaren Generating Station, part of the Public Service Electric and Gas Company system, is the first station in operation to have used steam at 1050 degrees Fahrenheit. The semi-outdoor boilers, shown at right, were also an innovation in this latitude.

Sewaren coal tower has peak capacity of 700 tons per hour. American Blower Type L and Type T Gyrol Fluid Drives greatly simplify the coal-handling operation.



Close-up of one of Sewaren's eight American Blower Induced Draft Fans. Six are rated at 227,000 cfm of gas at 18.6" sp; two at 235,400 cfm of gas at 17.5" sp.

Sewaren...a milestone in power development

Long-range planning by the Public Service Electric and Gas Company gave New Jersey one of the nation's most advanced generating plants — the Sewaren Generating Station, at Sewaren. It houses facilities which, even today, are among the most modern known to man, for it was designed with the future in mind.

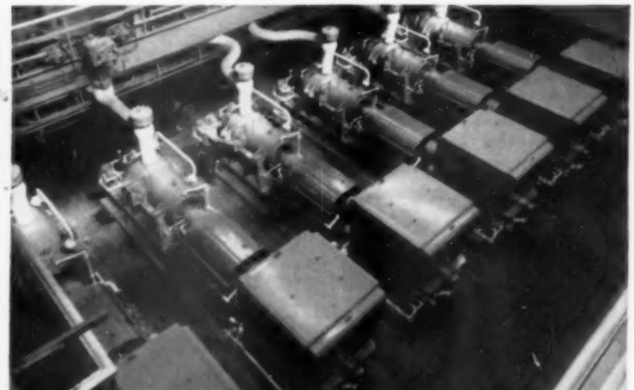
American Blower plays an important part in the operation of the Sewaren Generating Station. There are now *eight* Sirocco Induced Draft Fans, two equipped with Gýrol Fluid Drives, and *eight* American Blower HS Forced Draft Fans, each of which is also driven through Gýrol Fluid Drives. Rated at 2000 hp at 3465 rpm, twelve additional Gýrol Fluid Drives provide adjustable speed control of boiler-feed pumps.

What are your plans for the future? If they include expanding or modernizing your facilities, contact your American Blower or Canadian Sirocco Branch Office, now.

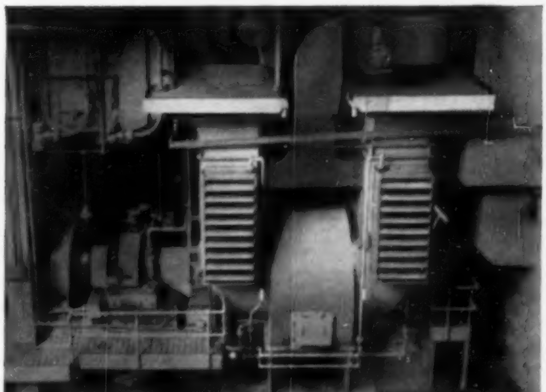
AMERICAN BLOWER CORPORATION, DETROIT 32, MICHIGAN
CANADIAN SIROCCO COMPANY, LTD., WINDSOR, ONTARIO

Division of American-Standard

AMERICAN BLOWER



Shown are six of the twelve boiler-feed pumps equipped with American Blower Type VS Class 6 Gýrol Fluid Drives, which are designed for high-speed applications.



This close-up shows one of eight American Blower Forced Draft Fans. Six have capacities of 123,000 cfm of air at 22" sp; two have capacities of 190,000 cfm of air at 15.0" sp.

for the man considering a PACKAGE BOILER

new all-electric METERING TYPE PACKAGED CONTROL by HAYS

Now available for *all* makes and sizes of water tube type package boilers is the new all-electric, metering type Hays packaged control.

Metering type control provides maximum combustion efficiency regardless of the fuel burned because it *actually meters* the fuel flow and air flow, and automatically maintains the desired ratio. No adjustments are needed when changing fuels or oil burner tips.

All-electric operation includes not only safety devices but also steam, fuel, and air controllers and valves—uses only the normal source of AC voltage. No compressed air is required.

Fully automatic, safe and reliable operation is assured because Hays maintains the same industrial quality built into the largest utility combustion control system and it is factory tested before shipment.

Complete package in one simple and inexpensive to install panel board.

Write today for fact-filled Bulletin 53-1088-239.

THE hays CORPORATION

MICHIGAN CITY 1, INDIANA

Automatic Combustion Control • Veriflow Meters and Veritrol • Electronic Oxygen Recorders • CO_2 Recorders Boiler Panels • Gas Analyzers • Combustion Test Sets Draft Gages • Electronic Flowmeters • Miniature Remote Indicators • Electronic Feed Water Controls

For your new **PACKAGE BOILER...**

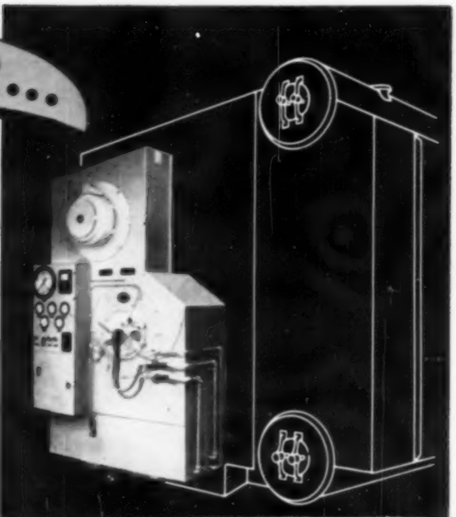
The new COEN
FYR-COMPAK

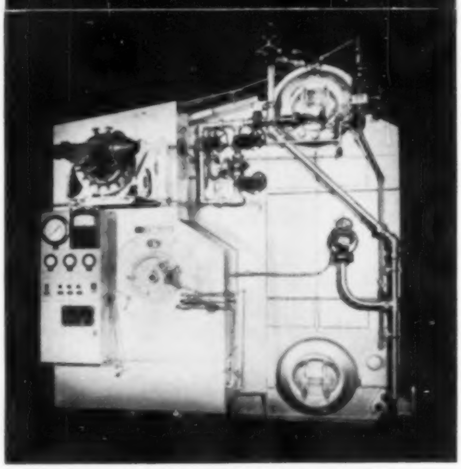
PATENTS APPLIED FOR

PACKAGED BURNER
(Oil, Gas or Combination Oil and Gas)

BURNER, WINDBOX and FAN

BURNER PIPING,
COMBUSTION and SAFETY CONTROLS





Upper Photo — Combination Gas and Oil for CE "VP" 30,000 pph package boiler.
Lower Photo — Oil only — Turbine drive for CE "VP" 30,000 pph package boiler.

in a simple, compact Boiler Mounted Assembly

1. For D-Type furnace arrangements with Boiler Mounted Control Center beneath (as illustrated).

or 2. For balanced furnace arrangements with Boiler Mounted Control Center to either side.

3. Minimum Trim Model—Control Cabinet only.

or 4. Standard Trim Model (as illustrated)—includes Miniature Panel above Control Cabinet with addition of flush mounted Boiler Gage, Draft Gage, Fuel Pressure Gages and Remote Manual-Automatic Control Station.

5. Fully Automatic or Semi-Automatic (push button elec-gas ignition).

The New COEN FYR-COMPAK includes **all** the many advantages of the efficient wide range COEN PAC-O-MATIC Package Burner plus these **outstanding innovations:**

- Integral Flush Front Windbox-Fan Housing with **Centrifugal** Fan.
- Streamline **discharge** damper (in place of fan inlet damper with its "noise" at low loads).
- The **quietest** fan arrangement yet offered (fan inlet facing boiler, **not** facing room).

FYR-COMPAKS sold and on order for Combustion Engineering "VP" package boilers during 4 months since its introduction totaled 15 as of March 15, 1955.

Write for COEN FYR-COMPAK Specifications and "*Why Coen?*"
(a complete checklist of COEN features and advantages).

COEN COMPANY

COMBUSTION ENGINEERS · DESIGNERS · MANUFACTURERS

COEN

OIL AND GAS BURNER EQUIPMENT FOR INDUSTRY

MAIN OFFICE AND PLANT: 40 BOARDMAN PLACE, SAN FRANCISCO 3

Eastern Agents and Warehouse — Coen Burner Co., P. O. Box 7, Union City, New Jersey

EASTERN CANADA
Burner Equipment Limited
3204 Rachel Street
East Montreal, Canada

PHILADELPHIA AREA
J. J. White
P. O. Box 454, Flourtown, Pa.

GREAT LAKES
P. P. Schoonhoven
228 N. La Salle, Chicago, Ill.

SO. INDIANA—KENTUCKY
Ralph M. Barnes
3550 No. Hawthorne Lane
Indianapolis 44, Indiana

ST. LOUIS AREA
Laclede Stoker Co.
4438 Hunt Ave., St. Louis 10, Mo.

MIDWEST
The Walling Co.
1504 Dodge St., Omaha, Neb.

MIDWEST
The Walling Co.
P. O. Box 728, Newton, Iowa

GULF SOUTHWEST
J. Newell Royall
P. O. Box 544, Houston, Texas

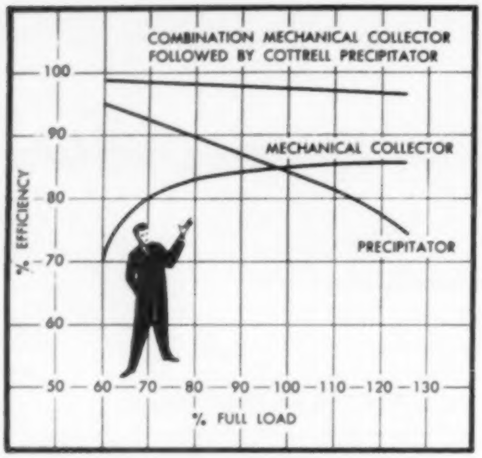
MOUNTAIN STATES—DENVER
Thermo Tech Prod. Co., Box 4148
So. Denver Station, Denver, Colo.

MOUNTAIN STATES—SALT LAKE CITY
Pace Turpin Company
726 South Third West Street
Salt Lake City, Utah

NORTHWEST
Northwest Industrial Service Co.
538 First Ave. South, Seattle, Wash.

SOUTHWEST
A.H. Merrill Engineering Co.
1238 S. Atlantic Blvd., Los Angeles, Cal.


Proof of PERFECT* Water Treatment PERFORMANCE
Nearly 12 billion pounds of steam have been generated inside this boiler and its twin. Boilers have never been acid cleaned. Tubes have never been turbined. All water side surfaces are clean-to-metal.
TURN THE PAGE FOR MORE FACTS ON HOW IT WAS DONE
*We at Nalco think at least 99%!



Advantages of the Western Precipitation CMP Unit

for recovering solids from stack gases in public utility operations

The control and recovery of fly ash from stack gases has always been a troublesome problem in public utility operations. With the development of the CMP unit by Western Precipitation Corporation, new economy and efficiency in the solution of fly ash problems are now possible.

Almost a half century ago Western Precipitation pioneered the first commercial application of the now-famous Cottrell Electrical Precipitator to recover suspensions *electrically*, and this equipment is still unsurpassed in its field.

Subsequently, to provide efficient fly ash recovery for low cost installations, Western Precipitation also pioneered the first small tube *mechanical* recovery unit — the Multiclone Collector — and this unit promptly gained widespread recognition for the new efficiencies it brought to mechanical recovery processes.

Combination Multiclone-Precipitator Unit. From these years of experience gained in both Cottrell and Multiclone installations, Western Precipitation recently offered another new development — the CMP Unit — a unit that combines in one compact installation many of the best features of both electrical and mechanical recovery methods.

In a typical CMP Unit, the stack gases first pass through a Multiclone section where the heavier materials are removed *mechanically*.

The partially-cleaned gases then pass through a Cottrell section where the very small particles are removed *electrically*.

This arrangement offers several advantages important to public utilities. Removing the heavier particles by the Multiclone process permits the bulk of the recovery operation to be performed with relatively low-cost equipment. Using a Cottrell for the final clean-up insures unusually high recovery efficiency — approaching theoretically perfect, if desired. Thus, the CMP combines high recovery efficiency with low total cost . . . and, as shown in the chart above, has the further advantage that the efficiency curve of the Multiclone portion complements that of the Cottrell portion — *therefore the overall CMP efficiency remains practically uniform at all boiler loads.*

At low boiler loads the recovery efficiency of the Cottrell is highest, while that of the Multiclone reaches its maximum at high boiler loads. But, by combining the two types of equipment into a *single* CMP unit, the efficiency curve remains almost flat whether the boiler load is low or high.

With CMP equipment, even small utility companies can now afford adequate fly ash recovery. However, it is important to remember that full benefit of the CMP principle can be obtained only by a proper balance between the mechanical and electrical sections to fit the individual requirements of *each individual* installation. And no organization is better equipped to provide this critical "know-how" than the organization that provides integrated responsibility for Cottrell, Multiclone and CMP methods . . . *the Western Precipitation Corporation.*

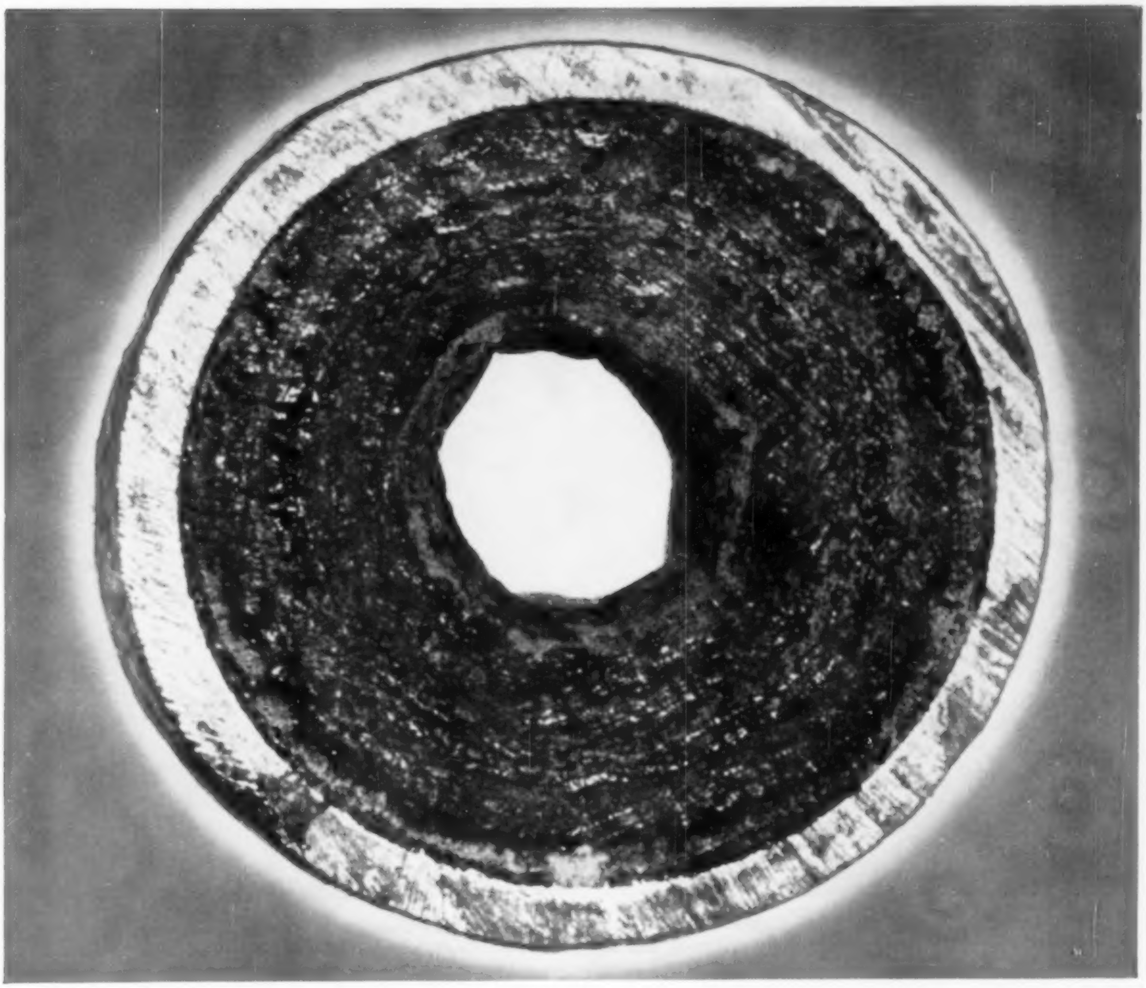
This unique background of experience in the solution of fly ash recovery problems is available from our office nearest you. May we give you more complete details?

Western Precipitation Corporation

DESIGNERS AND MANUFACTURERS OF EQUIPMENT FOR COLLECTION OF SUSPENDED MATERIALS FROM GASES & LIQUIDS

Main Offices: **1022 WEST NINTH STREET, LOS ANGELES 15, CALIFORNIA**

Chrysler Bldg., New York 17 • 1 N. La Salle St. Bldg., Chicago 2 • 3252 Peachtree Rd. N.E. Atlanta
Hobart Bldg., San Francisco 4 • Precipitation Co. of Canada, Ltd., Dominion Sq. Bldg., Montreal



END OF THE LINE

SCALE—layer upon layer of it—has reduced the inside diameter of this pipe to practically nothing. It's a common occurrence in some power plants, and the results are costly. The line must be taken out of service. That means production loss and expensive maintenance or replacement.

Scale, sludge, carry-over, and return-line corrosion are but a few of the problems that must be overcome to assure efficiency in boiler plant operation. In Dearborn's complete line of water conditioning products, there is the correct treatment to eliminate every water trouble—the properly balanced treatment to reduce unnecessary maintenance, avoid shutdowns, and protect valuable equipment.

Since 1887, Dearborn products have provided trouble-free water to users of steam in all types of industry. That's why, today, power engineers in leading industrial plants throughout the nation look to Dearborn for consultation and assistance in solving their water treating problems.

MAIL THE COUPON

Dearborn Chemical Company, Dept. Com
Merchandise Mart Plaza, Chicago 54, Ill.
Please send me complete information on Dearborn Water Conditioning.

Name.................................*Title*..................

Company..

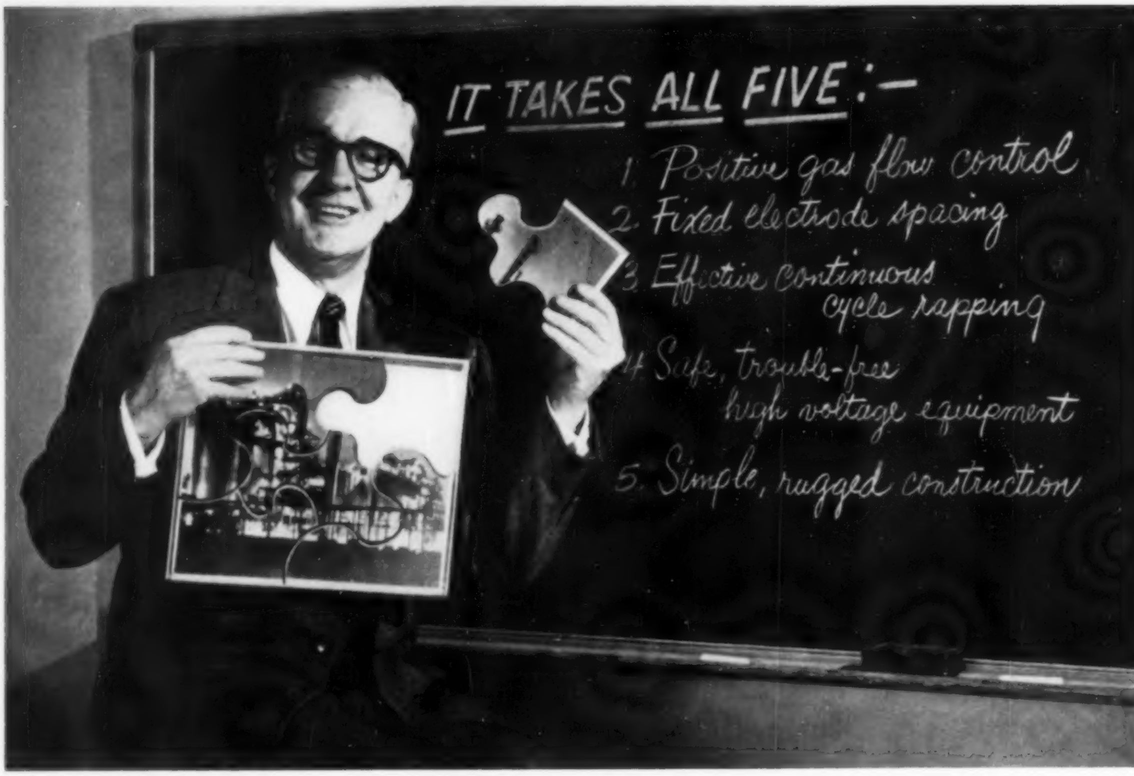
Address..

City.........................*Zone*....*State*..................

Dearborn®

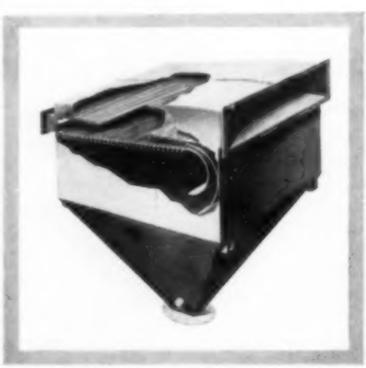
...a leader in water conditioning
and corrosion control

Buell 'SF' Electric Precipitators meet all 5 basic requirements for TOP EFFICIENCY

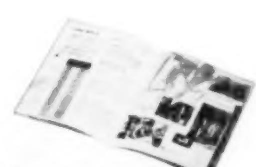


A slight deficiency of any single factor would be sufficient to impair the performance or service life of any dust recovery system. The constant top efficiency of Buell installations is the result of skillfully adjusting all five elements to best meet various operating conditions . . . provide consistent top efficiency.

Buell Cyclone Collectors are noted for their efficiency, too. Here are exclusive reasons why: shave-off design which harnesses back-flow and puts it to work . . . plus extra large diameter design to prevent "plugging."



Buell "LR" Fly Ash Collectors are ideal for low and high pressure boiler operations up to 2000 BHP, with either natural or mechanical draft. Check them for high efficiency, simple design, compactness, flexibility in layout.



FREE BOOKLET!
"The Collection and Recovery of Industrial Dusts"
Write to:
Buell Engineering Company,
Dept. 70-L, 70 Pine Street,
New York 5, New York

buell®

MECHANICAL ELECTRICAL *Experts at delivering Extra Efficiency in* **DUST COLLECTION SYSTEMS**

Hall Industrial Water Report

VOLUME 3 DECEMBER 1955 NUMBER 6

It Takes a Lot of Water to Process Food

In this 60-billion-dollar-a-year business, Hall helps to keep production up by keeping troubles with water down in plants from Massachusetts to California and from Florida to Washington. Not only the conditioning of water for steam power and steam heating, for cooling and for cleaning and processing, but also the processing of waste water for re-use, requires expert consultation and continuing service.

Maintenance Reduced in Plant Condensate System

Severe corrosion was being experienced throughout the condensate system of an Eastern chocolate manufacturing plant, with periodic replacement of sections of return line. Robert Dow, service engineer in the Boston office of Hall Laboratories, suggested a survey with corrosion test specimens to determine how much the use of Hagafilm® might improve conditions.

Weight losses on the test specimens before treatment revealed corrosion rates in most of the return lines sufficiently high to justify treatment. Simple gravity feed of Hagafilm to the boiler feedwater at the suction side of the boiler feed pump was accordingly started.

During the first three months, old corrosion products loosened by the action of the filming amine occasionally plugged traps and strainers. Then the intervals between maintenance calls lengthened until six months would elapse without a single call for a trap to be cleaned or a corroded pipe fitting to be replaced.

When Bob Dow suggested further tests with specimens to measure the effectiveness of the Hagafilm, plant personnel said they already had all the evidence they needed.

Sweetened Boiler Water Not to Plant's Taste

A call for help reached Hall engineer Robert Hobek from a fruit processing plant in Kentucky. Carryover from a boiler suggested that a slug of sugar syrup had somehow leaked into the condensate return system.

Steam coils used to heat some of the processing vats were immediately suspected, since the vacuum created when the steam was shut off could suck the liquid from a vat through any leak in the coil. A careful check revealed the expected perforation in one of the coils. This was repaired and all other coils were checked.

Most of the cooking was done with jacketed kettles so a drain valve was installed on each steam jacket, to be left open at the end of each day. In the morning the steam inlet valve to each jacket was partially opened and the first condensate running out of the drain valve was checked visually for any color indicating contamination.

Jacketed equipment is now used exclusively in the plant. No further difficulty with the sweetened boiler water has been experienced.

Fungus Attack on Cooling Tower Stopped

A mossy organic growth found in patches above the spray line in the top of their cooling tower was cause for concern to an Eastern food processing plant. Hall Laboratories' representative Jack White hurried samples to Hall headquarters in Pittsburgh for examination.

Out of the laboratory came the report that the damaged wood was infected with the same destructive fungus which had played havoc with a number of cooling towers in the Gulf Coast area, in one instance to the extent of $100,000 a year for replacement of wood.

Quick direct treatment of the wood was necessary. Hall engineer Ed Stewart arranged to have the plant personnel spray the cooling tower three times in a month with a trichlorphenate compound, soaking the wood thoroughly each time. An inspection then showed no signs of fungus attack in the zone where previously it had been severe. The plant has continued to spray the tower periodically with excellent results. No sign of fungus attack has yet appeared on a test board installed in 1953.

Plants which are not able to shut down periodically for spraying can protect the wood for prolonged periods by treating it successively with two water-soluble chemicals which interact to form a precipitate with fungicidal properties deep within the wood.

Hall Helps Hams

Hottest development in the curing of hams is an invention by G. O. Hall of Hall Laboratories described in U. S. Patent 2,513,094, now being developed commercially by Calgon, Inc., under the trade-mark Curafos.® By the properly controlled use of complex phosphates in the pumping pickle injected into the ham to produce the cure, the meat will retain its attractive color even when sliced and exposed to fluorescent lights at retail meat counters.

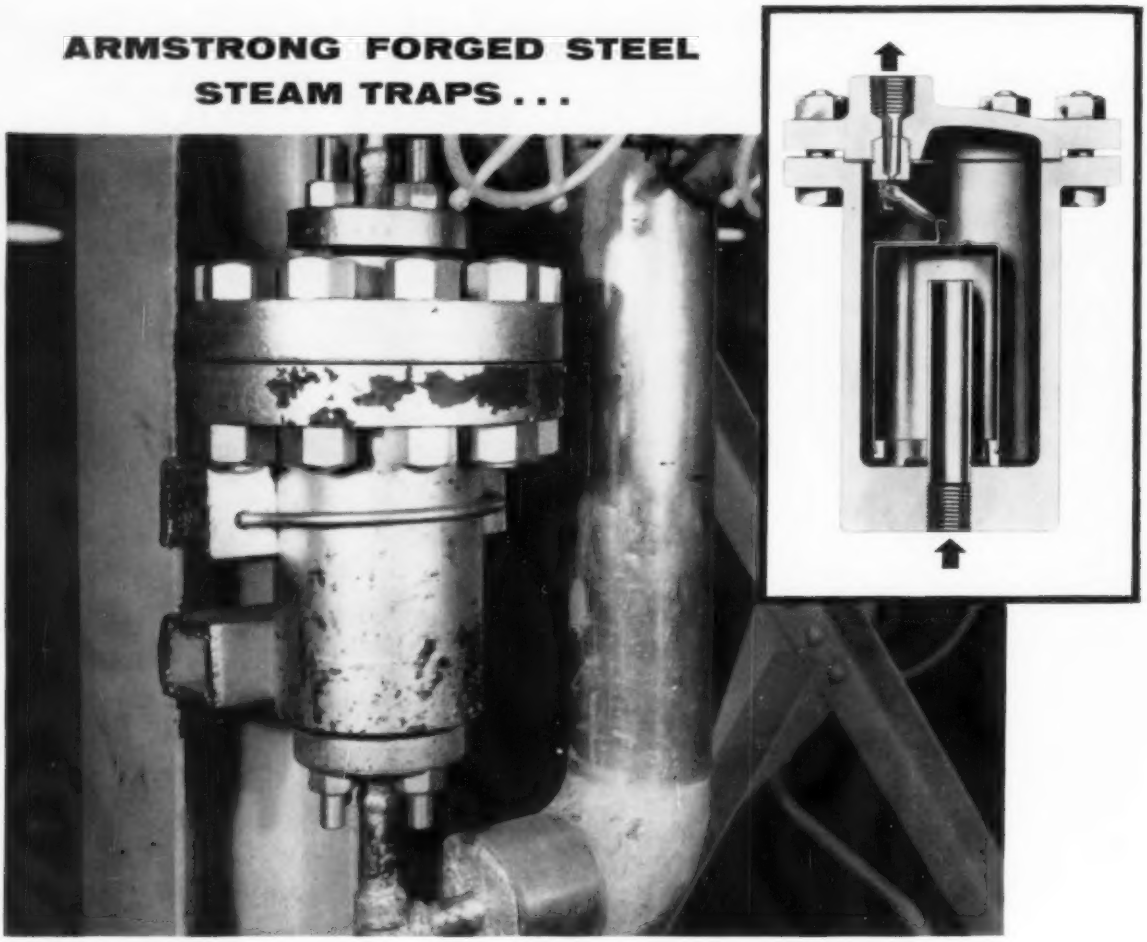
Industrial Water Problems Require Special Handling

There are no "stock answers" to industrial water problems. For information, write, wire or call Hall Laboratories, Inc., Hagan Building, Pittsburgh 30, Pa.

Water is your industry's most important raw material. Use it wisely.

Hall Laboratories, Inc.—Consultants on Procurement, Treatment, Use and Disposal of Industrial Water

ARMSTRONG FORGED STEEL STEAM TRAPS . . .



. . . the Best Answer to Superheated Steam Line Drainage, because:

LIST OF MATERIALS
ARMSTRONG FORGED STEEL TRAPS

Part	Material
CAP AND BODY FORGINGS	
Up to 600 psi, 750°	1030 carbon steel
Up to 900 psi, 900°	ASTM Spec. F-1 carbon moly steel
Up to 2500 psi, above 900°	ASTM Spec. F-5 chrome moly steel
VALVE AND SEAT	Type 440 chrome steel, heat treated, standard. Stellite available.
LEVER MECHANISM	Stainless steel
BUCKET	Stainless steel
BOLTS	Class C high tensile, high temperature bolting material—125,000 min. tensile.
NUTS	Hex, semi-finish, heat treated for high pressure, high temperature service.
GASKET	Compressed graphited asbestos
INLET TUBE	Wrought iron

1. **Proved** in service in leading power plants throughout the world at pressures to 2400 psig.

2. **Experience** of Armstrong in design, manufacture and application dates back to the *beginning* of the trend to higher and higher pressures.

3. **Automatic** safety assured because of high capacity for warm-up loads; traps don't "forget" to drain the lines, and Armstrong traps *always* open for condensate.

4. **Economy** assured because of high value for price, long life with infrequent maintenance and freedom from steam loss.

5. **Quality** of workmanship and materials that is backed by a "complete satisfaction or your money back" guarantee.

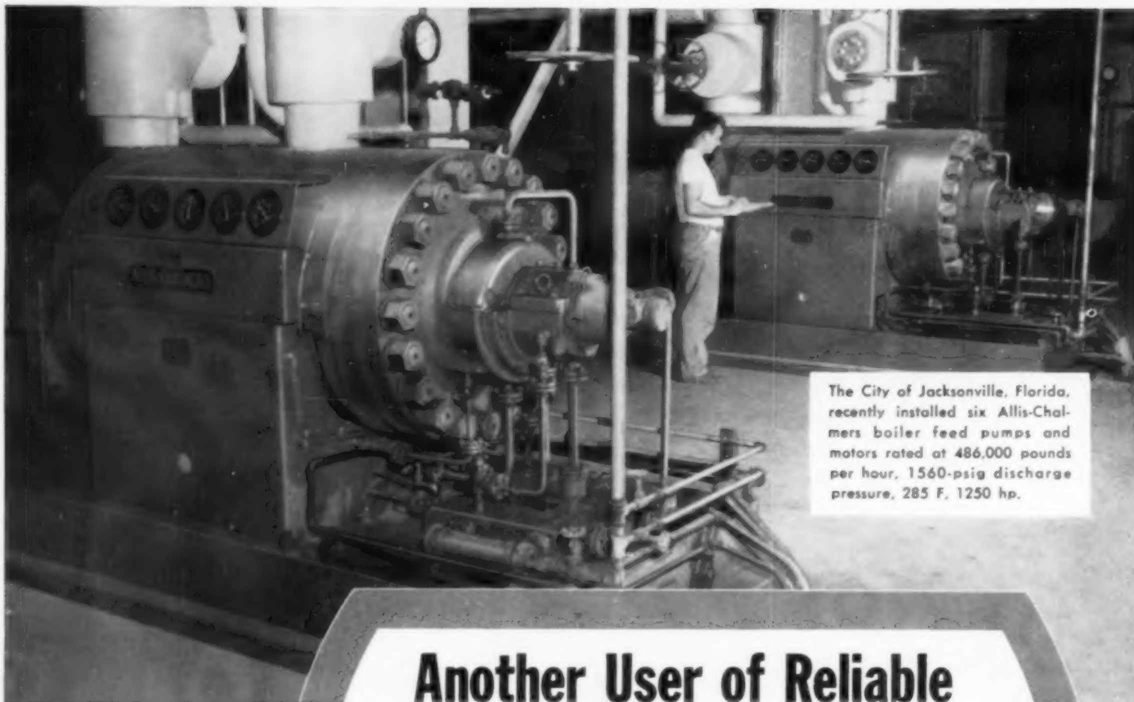
SEND FOR THIS LITERATURE:

1. **Should we trap superheated steam lines?**—the answers of 11 engineers who have used traps for this service.

2. **Catalog J**—complete data on forged steel traps and steam trapping.

Application Engineered
STEAM TRAPS

ARMSTRONG MACHINE WORKS, 814 Maple Street, Three Rivers, Michigan



The City of Jacksonville, Florida, recently installed six Allis-Chalmers boiler feed pumps and motors rated at 486,000 pounds per hour, 1560-psig discharge pressure, 285 F, 1250 hp.

Another User of Reliable ALLIS-CHALMERS barrel-type PUMPS

City of Jacksonville

Here are the reasons for wide acceptance of these pumps:

- Outstanding performance — fully proved by service records.
- High efficiency and smooth operation under fluctuating loads — first stage has twin, single-suction impellers for low NPSH requirements.
- Simple maintenance—expansion joint and shaft seals are brought to outside of pump where they can be easily inspected.
- No balancing device needed—axial balance is maintained by back-to-back mounting of the impellers.

THERE are outstanding features like these throughout the Allis-Chalmers line. Whether you require boiler feed, condensate, circulating or other power plant pumps — it pays to standardize on Allis-Chalmers.

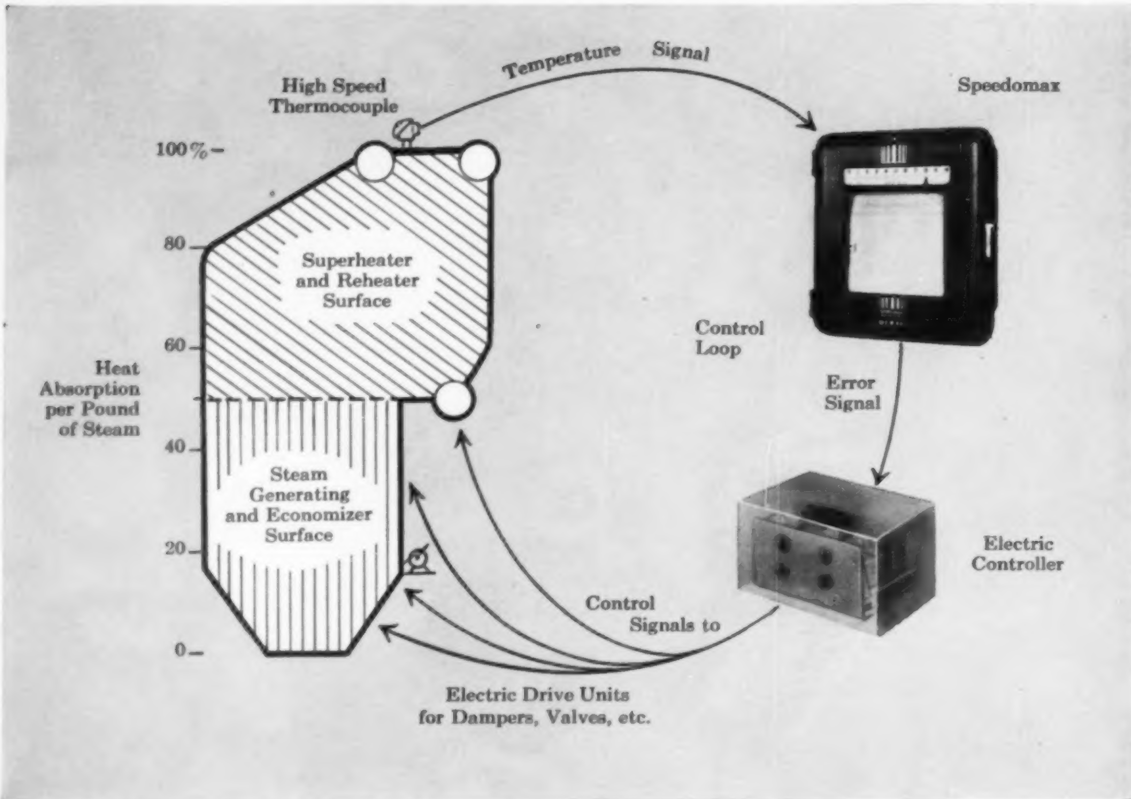
In addition, A-C can supply pumps, motors and control of coordinated design and manufacture. This means one responsibility — one guarantee of satisfaction.

Get complete information on barrel-type boiler feed pumps. Call your nearby A-C office or write Allis-Chalmers, General Products Division, Milwaukee 1, Wisconsin for Bulletin 08B7899.

A-4854

ALLIS-CHALMERS

A-C ALLIS-CHALMERS


Temperature Signal
High Speed Thermocouple
Speedomax
100%
80
60
40
20
0
Superheater and Reheater Surface
Heat Absorption per Pound of Steam
Steam Generating and Economizer Surface
Control Loop
Error Signal
Electric Controller
Control Signals to
Electric Drive Units for Dampers, Valves, etc.

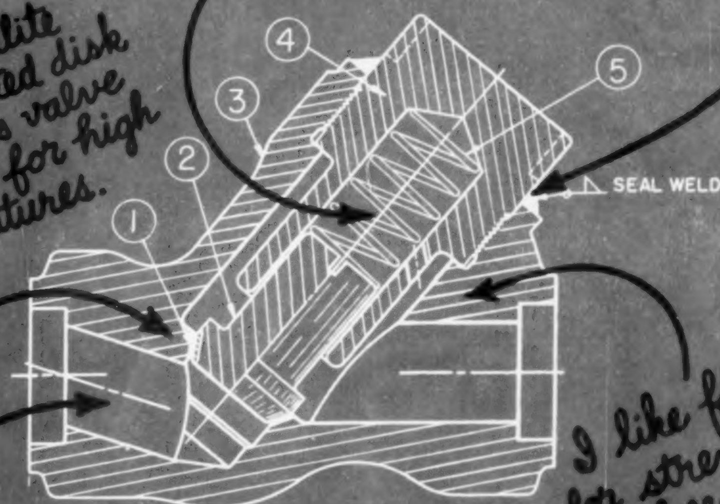
J. B.—
Here is the
check valve
companion to
the Edward Univalve.
R. G. P.

ROCKWELL BUILT
Edward Valves

Proven seal-welded joint. Permanently tight yet readily disassembled.

Edward has used this disk-guide-spring design in small checks for many years. Gives excellent alignment and is dependable.

Integral Stellite seat, Stellited disk make this valve suitable for high temperatures.



Straight-through flow is important. Prevents erosion—keeps seating surfaces clean.

Ask Edward to quote—including these checks.

I like forgings for strength and freedom from porosity. This valve is all forged.

By the way, Edward builds these in 1500 and 2500 pressure classes.

LIST OF MATERIAL
QUANTITIES ARE FOR ONE GLOBE OR ONE ANGLE VALVE
WHERE A.S.T.M. SPECIFICATIONS ARE INDICATED THE LATEST REVISION APPLIES

PIECE NO.	NAME OF PIECE	NO. REQ'D.	MATERIAL	SPECIFICATIONS	EDW. MS NO.
1	SEAT	1	INTEGRAL WITH BODY	STELLITED	483
2	DISK	1	FORGED ALLOY	A.S.T.M. A182 GRADE F11	227
			STEEL WITH STELLITED SEATING FACE		481
3	BODY	1	F. ALLOY STEEL	A.S.T.M. A182 GRADE F11 (a)	227
			F. ALLOY STEEL	A.S.T.M. A182 GRADE F22 (b)	230
4	BONNET	1	F. ALLOY STEEL	A.S.T.M. A182 GRADE F11 (a)	227
			F. ALLOY STEEL	A.S.T.M. A182 GRADE F22 (b)	230
5	SPRING	1	STAINLESS STL.	A.S.T.M. TYPE 302	253

EDWARD VALVES, INC.
SUBSIDIARY OF ROCKWELL MANUFACTURING CO.
EAST CHICAGO, INDIANA

LIFT TYPE CHECK VALVE
GENERAL ASSEMBLY
FIG.-2278 SIZES ½, ¾, 1, 1¼, 1½, 2

DRAWN
CHK'D
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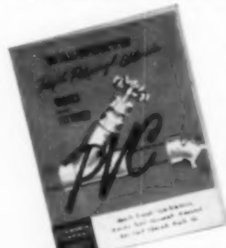
Walworth PVC Y-Globe Valves are designed to regulate the flow of alkalis, acids, inorganic salt solutions and other troublesome fluids commonly found in food, chemical and allied industries. They will give exceptional service at temperatures as high as 150°F and are designed for use with schedule 80 pipe. Other features of these valves include: (1) Three chevron, Teflon packing rings give you a leak-proof seal without binding the stem. (2) No useless threads to accumulate troublesome dirt because no stem threads enter the interior of the body. (3) Snap-on spherical plug with ball-to-cone seating arrangement to assure a tight line-contact seal between disc and seat regardless of any minor inaccuracies in alignment. (4) Full 45° angle of stem with center line of pipe to reduce pressure drop and turbulence. (5) Generously designed flow passage at the valve seat for a more even flow. (6) Back seat design allows repacking when wide open under pressure. (7) Polyethylene bonnet gasket to assure a perfect body-to-bonnet seal.

Walworth PVC Diaphragm Valves come equipped with neoprene discs. Other diaphragms especially suited to your application can be furnished. "R-2" rubber diaphragms are commonly used in systems handling dilute acids and alkalis. "J-1" Teflon diaphragms are recommended for maximum chemical resistance.

Valve design features: (1) No stuffing box or packing to replace. (2) A resilient diaphragm connected to the compressor by a stud assures a leakproof closure on the body weir or valve seat even when slurries or semi-solids are in the line. Diaphragm easily replaced without removing the valve from the line. (3) Streamlined flow area in valve body makes valve self cleaning and allows fluids to flow equally well in either direction. (4) Separation of valve body from the sealed metal bonnet protects fluids from contamination. Fluids contact only the valve body and diaphragm. (5) Completely enclosed metal bonnet protects stem from breakage and distortion.

Walworth PVC Fittings assure uniform thermal expansion of pipe and fitting threads when used on plastic pipe. They eliminate the danger of jammed threads, loose joints and the chance of galvanic corrosion. These screwed pipe fittings are: (1) Designed for use on schedule 80 of plastic pipe. (2) Walls are of uniform thickness accurately molded. Proportions are skillfully worked out in all sizes and types of fittings. (3) Fittings are chamfered to protect the thread and afford easy entrance of the pipe. Long bands provide reinforcement at the points of severest strain.



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General View of Green River Power Station
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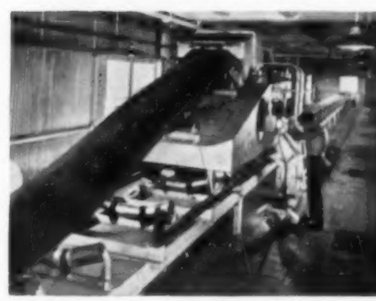

Discharge Chutes of this Bartlett-Snow Motorized Travelling Tripper are Fitted with Plows and Rollers that Open and Replace the Bunker Seal Assuring Dust-Free Operation

View of Open Belt Conveyor Gallery. Protecting Hoods are Hinged on One Side and can be Latched in Either Open or Closed Position

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COMBUSTION

Editorial

A Source of Renewed Confidence

Last January our editorial entitled "A Solemn Reminder" commented on the risks and uncertainties underlying several turbine-generator failures which took place during 1954. The concluding paragraph of the editorial read as follows:

"This is not a time to become alarmed and fearful of safety conditions in central stations. By the very rarity of their occurrence, such accidents attract a great deal of attention. Undoubtedly the lessons learned therefrom will be widely publicized in accordance with the admirable tradition of the utility industry of making such information generally available. The lives so tragically lost at Ridgeland cannot be regained, but the memories of these supreme sacrifices in the line of operating duty serve as a solemn reminder of the inherent risks in engineering advances."

It is indeed gratifying to be able to report that the results of the investigations of the turbine-generator failures mentioned in the earlier editorial are now available to the utility industry and to the entire engineering profession. At the 1955 ASME Diamond Jubilee Annual Meeting held in Chicago in mid-November, a six-paper symposium on the subject of materials failure in rotors of large steam turbine-generators was presented under the auspices of the Power and Metals Engineering Divisions. Experimental and analytical resources of turbine designers, applied mechanics specialists, metallurgical consultants and those in the heavy steel industry familiar with the casting and forging of large ingots for turbine-generator rotors were combined in the preparation of the six outstanding technical papers that made up the symposium.

Perhaps the most encouraging outcomes are related to the establishment and independent verification of the causes of failure and to the narrowing of the areas of uncertainty. This combination of newly acquired knowledge already subjected to laboratory verification and more nearly complete understanding of precipitating factors and causes of failure affords renewed confidence both to the designer and user of large steam turbines.

As long as uncertainty remains, however small it may be, further investigation and research are desirable. The authors of the symposium papers emphasized the need for better inspection techniques to determine, in a manner consistently reproducible, the type of minute flaw or chemical inclusion that might contribute to rotor failure. They also urged that more attention be given to vacuum casting techniques, which apparently have been developed to a higher degree of commercial acceptability in Germany than in this country.

Engineering advances will always be subject to inherent risks that may cause equipment and material failure. What is most reassuring is that the turbine builders and their suppliers have met the challenge of the 1954 mishaps, have conducted investigations that provide clear-cut causes of failure and are now in a position to design even larger machines in the future with increased confidence in their mechanical safety.

The ASME Annual Meeting in Retrospect

At the time of the last Annual Meeting of The American Society of Mechanical Engineers we expressed in the lead editorial of our December issue a concern that too much effort was being expended in building programs towards "the biggest ever" and at the expense of a loss in quality. This year's meeting, celebrating the Diamond Jubilee of the Society, could have suffered understandably from the same criticism. In our opinion, however, it did not and the Society's salute to its anniversary was tastefully handled and its technical program quite a cut above the preceding year's.

There were several rather outstanding sessions to our way of thinking. The highlight of the meeting was the session on supercritical pressure steam very ably chairmanned by Phillip Sporn, president, American Gas and Electric Service Corp. It fulfilled the basic purpose of any general meeting in that it served as a focal point for discussing openly the pros and cons of a major engineering step. A second very informative gathering because of its timeliness and general interest was the Furnace Performance Factors' meeting on corrosion and deposits from combustion gases.

If we may be permitted a suggestion there is still room for improvement in the handling of individual sessions and especially in the instructions to speakers. For example the average hotel meeting room is actually a dining room or a dance hall and has been designed to subdue noise. This acoustical treatment works against a speaker and we feel it incumbent upon the Society to assure itself that there is ample speech pick-up equipment properly located for the best possible listener reception. Along with this the Society should stress the importance of legibility on slides and set up some warning service on this item to those presenting papers so the viewing audience does not miss the major illustrative aids the author has employed to make his points.

A System of Charging for Steam in Industrial Plants with Power Generation[*]

By L. J. SFORZINI[†] and C. A. WINSLOW, JR.[‡]

Eastman Kodak Company, Rochester, N. Y.

Industrial plants with both steam loads and power services, the latter including electrical generation and in many instances also substantial amounts of mechanical power in the form of steam drives for refrigeration, compressed air, water pumping, etc., have a problem in determining how to collect and equitably allocate the charges for steam. Any system to meet requirements must be able to meet two fundamental conditions: (a) The system must accurately reflect the over-all results of operation of all power or utilities services, so as to permit checking and controlling costs; (b) it must accurately distribute the cost of all services to products at the various stages of manufacture.

A PLANT, such as a public utility, generating only electric power, has a relatively simple problem: All the steam generated is charged against electric power. Further, it has a ready index in that it can make a comparison with other similar plants on fuel use expressed as "Btu per kwhr."

In a single-type-product industrial plant these requirements may be met partially by a rather simple system collecting the cost of the various power services into a single account. This cost divided by the units of product output gives the cost per unit. Here it is not necessary to divide steam charges into process charges and charges to power. However, it does have one serious shortcoming in that it does not permit checking unit costs with other plants producing a different product; it can only check against its own past records or with plants producing an identical product. If one of the power services in "the package" has out-of-line costs it may go undetected for a considerable time.

When both steam and power are produced the problem becomes: Should the steam users be credited with all or part of the savings arising from the power by-product production incidental to steam use over an alternate source, say, either by condensing operation or purchasing the power? Or, should the steam users be charged for heat use at the same unit rate as power production, allowing the savings from the favorable balance to remain with the power producers? There are users and advocates of both methods.

The authors of this paper have had considerable experience with systems based on each of these premises.

Systems in Use

"Divided savings" systems must be based on assumptions made by engineers and accountants, or compromises by both, and usually no two systems in different plants will be found alike. In relatively simple plants with one or two steam pressures such a system might meet requirements and show logical results. However, if a plant expands and other pressures and equipment are added, and also if steam is used for utilities other than power generation, calculated savings in justifying expansion programs may show up as apparent losses on the cost sheets. As a result, continuous arbitrary modifications must be made.

One such system for supplying both process steam and back pressure and condensing power calculates power under condensing operation and allows steam to be the beneficiary of the combined production.[1]

Btu System

The system developed by the authors may be described as a "Btu System." The steam charge made against any piece of steam-using equipment is for the Btu it uses. In effecting changeovers from arbitrary systems it was found necessary to retain the concept of "pounds of steam" since production-plant operators through long use had become accustomed to the term and were reluctant to relinquish it. So we employed the term "standard pound of steam" and defined it as the addition or removal of a 1000 Btu of heat from a quantity of steam, or water, regardless of pressure or temperature conditions.

In calculating cost of steam production, the boiler output in multiple pressure and temperature plants is converted to "standard pounds of steam," or Btu, and a unit cost of production calculated. Off hand, it may seem that there should be an appreciable difference in

* Presented at the ASME Diamond Jubilee Annual Meeting, Chicago, Ill., Nov. 13-18, 1955, under auspices of the Power Division.
† Utilities Engineer, Consultant.
‡ Staff Assistant, Utilities Cost & Distribution, Kodak Park Works.

1 Beckmann, H., "Distribution of Power and Process Steam Costs in Industrial Plants," COMBUSTION, Vol. 25, No. 3, September 1953, pp. 55-56.

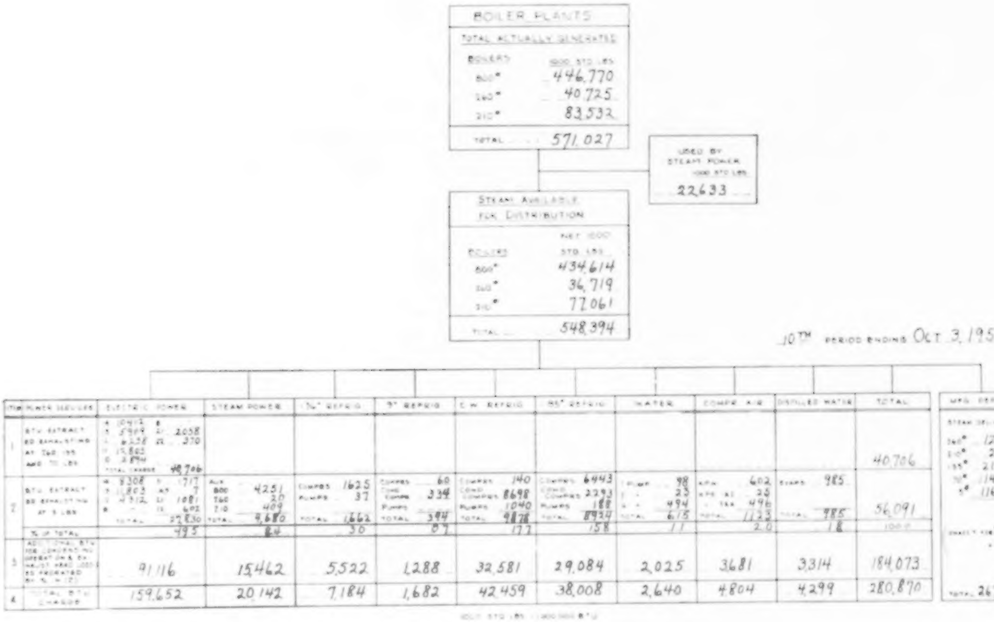


FIG. I SUMMARY SHEET – STEAM DISTRIBUTION

cost between a boiler installation installed for low pressure, say 150 psig, and one for high pressure, say 600 psig. Hence, if the requirements of a process user could be met with lower pressure boilers, it would be discriminated against in favor of the power units. A detailed study, however, would reveal that there would be no distortion, or that it would be of small order. This may be shown by the following:

1. The difference in investment between a 150 psig saturated plant and a 600 psig, 700 F plant is given by Mr. Melvin L. Jones of E. I. du Pont de Nemours Company, Inc., as 50¢ per pound per hour of steam capacity.[2] Writing this off at a fixed charge rate of 10 per cent a year means 5¢ per year, and with a 50 per cent steam plant load factor, this of itself would add only a little over 1 cent per 1000 lb, or per million Btu to the steam cost.

2. Combining steam and power production lowers the unit cost of steam to the steam user as the result of greater plant production.

3. High-pressure boilers, particularly if added to a low-pressure boiler plant, usually employ larger units, resulting in lower unit cost.

4. Most industrial plants use varying quantities of steam and electricity and there would be a small compensation through charges for the services made at various stages of manufacture.

There may be an important difference in installation cost in utilizing steam at various pressures. Low-pressure steam requires larger lines and more heating surface than higher pressure steam. The fact that high pressure may require a more expensive insulated line construction and handling of steam returns, including flashing, are compensating factors. Therefore, in setting up the system it was decided that the possible difference in costs did not justify a segregation of charges between pressure systems.

Steam Charges

In cases where the extracted or exhausted steam is completely to process, the steam charge for electric generation is the Btu removed from the steam passing through the unit plus the external losses such as machine bearings, radiation, and generator where winding heat is not recovered. The internal efficiency, and hence steam rate, is not a factor; if heat is not converted into mechanical energy, it remains to be used in process. A kwhr is by definition 3412 Btu and allowing for 5 per cent losses, a figure of 3600 Btu per kwhr becomes the steam charge. It is not necessary to meter the steam to make the charge; all that is required is to meter the electric output of a unit, although for steam-balance purposes the steam should be, and is, metered to all units.

In the case of mechanical drives where the extracted, or exhausted, steam is completely to process a similar charge of 2545 Btu per hphr is used, the external losses being taken as part of the driven load. The hphr are determined by various means, such as input to a similar electric machine, manufacturers' guarantees corrected to field conditions or by calculations.

In the case where the exhaust is to a lower pressure system which is supplied partially to process and part is rejected to atmosphere or condenser water, the sum of the kwhr and hphr of the portion of the output, or intake, of all units to or from this pressure is determined and is used to divide the charge for all such rejected steam. This is because they have produced a waste product for which there is no market. By this method the type of drive unit is installed for its effect on the plant as a whole, and not for its effect on a single service. For instance, condensing drives utilizing surplus low-pressure

[2] American Power Conference, March, 1955.

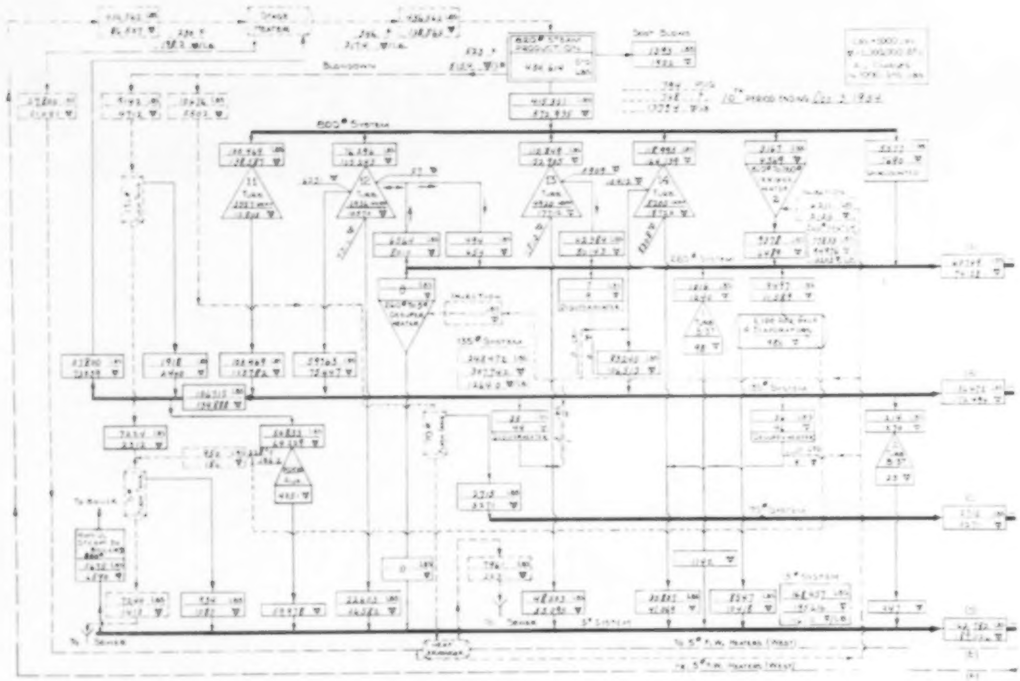


FIG. 2 STEAM DISTRIBUTION SUMMARY SHEET No. 1

steam could be installed on a refrigerating drive run in warm weather, yet an electric generating unit making this steam would also receive a portion of credit.

Interdepartmental Use of Power Services

Each power service is charged for a quantity of another service at the same cost as a process department. If it uses its own product it is again charged at the full unit cost. For instance, feed-pump drives for a steam plant may be electric or steam driven; in either case the steam plant is charged for so many kwhr or standard pounds of steam at the full distributed cost. An exception is made for soot-blowing, stoker humidification, and blowdown heat which is a waste and considered as not produced.

A stage heater does not use up heat; it merely transfers it from steam to water to be recirculated. Therefore, while it is appropriately considered in steam-balance calculations, no charge is made for it.

Application of System to a Plant

Fig. 1 shows a typical period (4 weeks) summary sheet for one of the plants using this system. Six distinct pressures, 800, 260, 135, 70 and 5 psig, as well as steam condensers, are involved. A good deal of metering, record keeping and many detailed sheets of tabulations were employed in producing this. A complete steam balance must be made each period. Books are closed on a Saturday and the following Wednesday a sheet such as this has been calculated, together with the quantity breakdown for the nine services into about 150 different accounts, and turned over to the accounting division. All this has been done by systematizing.

The "Total Actually Generated" is the total Btu converted from fuel to steam. It is the output quantity used in calculating boiler efficiency. The "Used By Steam Power" is for soot blowing, blowdown and stoker humidification steam. The difference between the two is "Steam Available for Distribution." The block labeled "Manufacturing Departments" is the sum of all metered and estimated uses for process plus a prorated share of the "Unaccounted For." "Unaccounted For" is the final difference resulting from the "Period Steam Balance." The difference between the "Steam Available for Distribution" and the "Manufacturing Departments" is the "Total to the Power Services."

Item No. 1 of Power Services is the 3600-Btu portion of the kwhr as already explained.

Item No. 2 is the kwhr and hphr equivalents of units, or portions of units, making or taking low-pressure steam. The total of this item is used in dividing up the remainder of the available steam or heat (item 3) which is for steam to steam condensers, to atmosphere through relief valves, radiation losses and line condensation and a pro rata of the "Unaccounted For."

Item 4 is the "Total" of the foregoing three items as shown in Fig. 1.

Steam Balance

Figs. 2, 3 and 4 show the "Steam Balance" used in determining the "Summary Sheet," Fig. 1. The starting point on each boiler-pressure system is the boiler meters. Then the boiler steam works its way to lower pressure systems mostly through metered units, with estimates in a few cases.

First, the entire steam system is balanced in pounds.

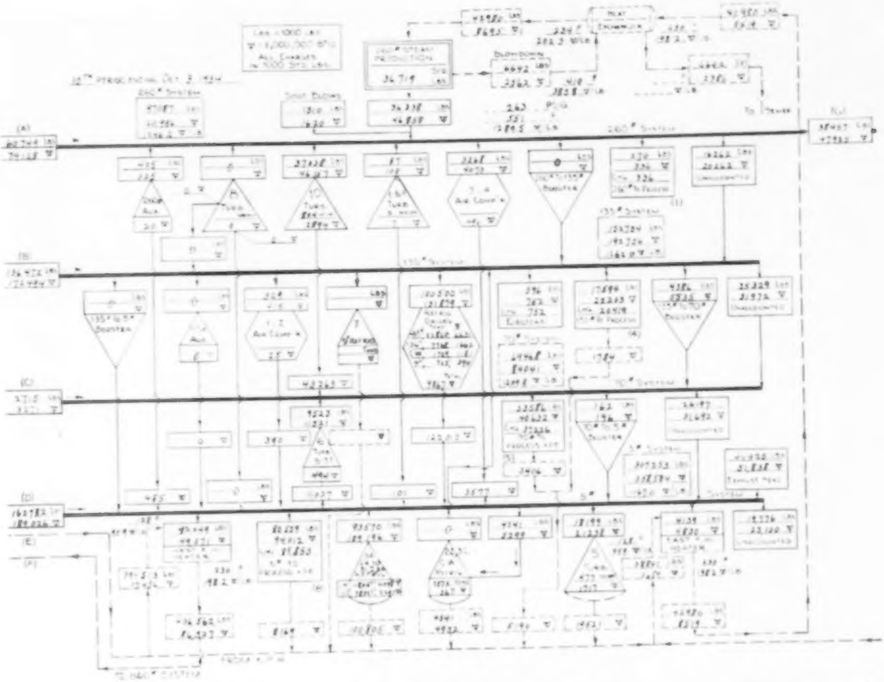


FIG. 3 STEAM DISTRIBUTION SUMMARY SHEET No. 2

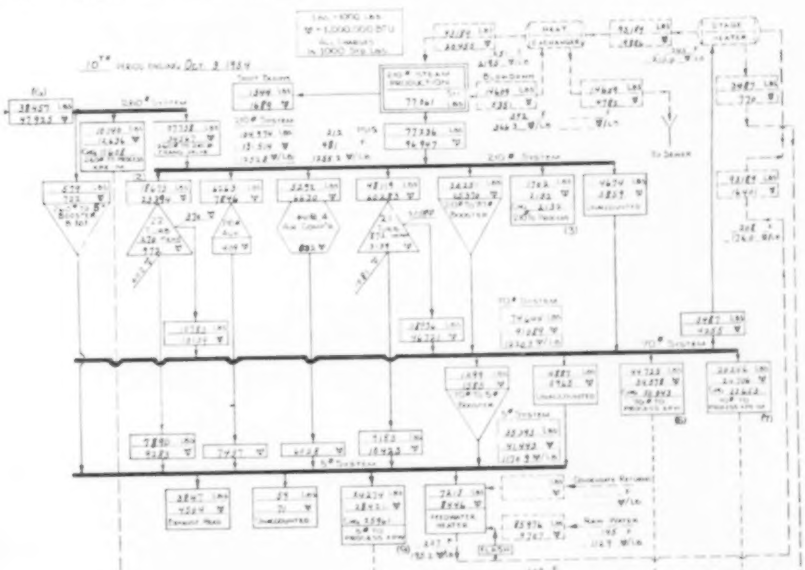


FIG. 4 STEAM DISTRIBUTION SUMMARY SHEET No. 3

The steam going into each system must equal what is coming from each system; the difference, if any, is put in the "Unaccounted for" block and passed to the next lower pressure system. This "Unaccounted For" represents meter limitations. The last "Unaccounted For" blocks from the 5 psig systems are the "Total Unaccounted" for the entire plant, averaging about 5 per cent for any year. This amount is prorated as already explained.

Next, the entire steam system must be balanced in Btu's. As the steam passes from one pressure to a lower one through the various drives, some Btu's are used up to make electricity, refrigeration, pump water, etc. The same pounds of steam come out of a turbine or engine as

go in, but the Btu's coming out are, of course, less.

The determination of the heat removed by electric generation in an extraction-back pressure turbine is by a formula method, based on metering the generator output, the throttle and the extraction steam, and the theoretical power available from throttle to the one or more extraction pressures and the exhaust pressure.

The calculation of the heat removed in a refrigerating turbine, or engine, drive is from a record of refrigeration-supply temperature, tonnage and head pressure. Standard curve sheets from which the horse-power can be read have been prepared for this purpose. Other mechanical drives are similarly calculated using appropriate data.

The steam supplied to process departments is metered for all large users and estimated for smaller ones. Each department is surveyed to determine the expected amounts of returns flash steam if any, and the return temperature, to determine the heat removed per pound. The water belongs to the Power Services Division and is merely a heat-transfer medium which it expects to get back. If the returns are used up internally, or rejected to sewer because of contamination, the process is charged with the heat represented by this.

Feedwater heaters are not final-use equipment; they are steam balance-improving equipment, replacing heat removed by process and power for which these are charged.

This particular plant has practically no condensing electric-generating units, the exception being a 1000-kw d-c turbine. It does, however, have a considerable number of refrigeration drives taking 5-psig steam and condensing it.

Figs. 3 and 4 show considerable exhaust head steam; i.e., steam rejected at 5 psig. While theoretically this may appear more expensive than some other alternate, say purchased power, it, however, represents sound economics. This is mostly steam produced in off-peak periods, hence at no fixed charges and with a fixed labor force; i.e., practically the only charges involved are fuel and cost of makeup.

We believe all other items are self-explanatory. The "Steam Balance" may appear rather complicated, but, as already stated, if set up as a system it becomes routine in period operations and it can be done rather easily and quickly by the clerical force. Two rather large plants have been using it for over 10 years and the results have justified continuing its use.

Related Cost System

Cost systems are outside the scope of this paper. We have merely described a method of allocating the units of steam production in an equitable manner. Hence, we have not shown unit costs. However, it may be of interest to state that over a year, this system shows a unit cost for electric power, considering all costs including that for a block of purchased power, slightly over half its purchased power unit cost.

Efficiency Index

With this system, it is rather easy to arrive at an index similar to that stated for a public utility, i.e., "Btu per equivalent kwhr." The term equivalent is used because the considerable block of mechanical horsepower must be considered for a true comparison. However, the electric power index can be calculated independent of the mechanical, if this is desired.

The sum of Items 1 and 2 in Fig. 1 divided by 3600 is the "Electric Power Production." This divided into Item 4 in this column is the Btu per kwhr from the steam and a further division by the boiler efficiency is the Btu per kwhr from the fuel. In a similar manner the total including mechanical drives can be calculated.

Typical Summer and Winter Distribution

Fig. 5 shows typical summer and winter distribution periods. This indicates the relative magnitude of the quantities of steam, or heat, involved in one of the plants using this system. It also indicates that there is surplus boiler capacity available in summer periods and for this reason the plant can consider fuel plus water makeup only in making economic comparisons for the off boiler peak power. We would also point out that the winter exhaust head steam and the relatively large amount of winter condensing steam are in transient stages which will be substantially reduced in the near future.

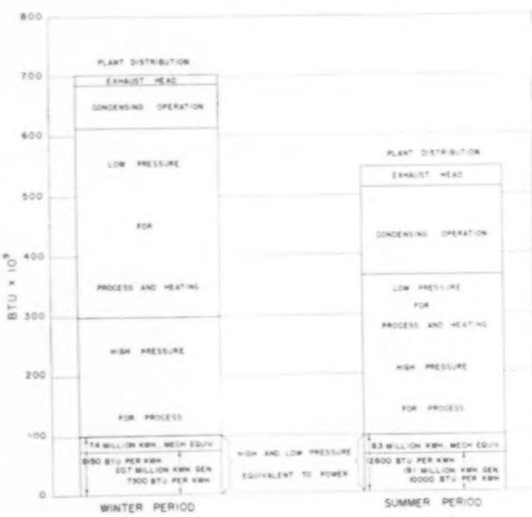


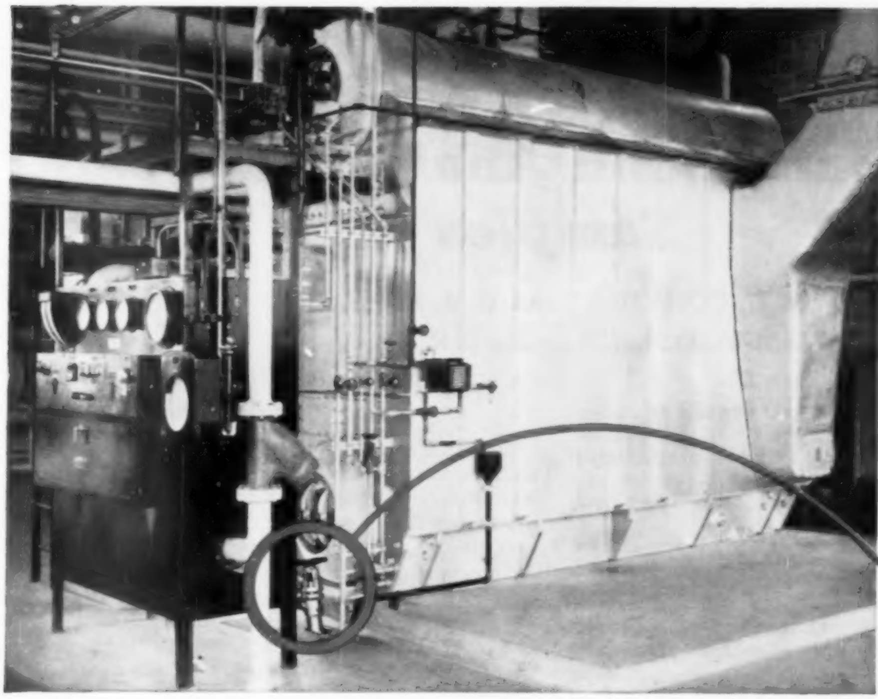
FIG. 5 TYPICAL DISTRIBUTION FOR A SUMMER AND WINTER PERIOD

The Btu per electric kwhr, 7300 and 10,000, respectively, for winter and summer, and 8150 and 12,600, respectively, per equivalent kilowatt including mechanical power, compares with annual figures averaging 9170 Btu per kwhr for the best utility plant and 14,854 Btu per kwhr for the lowest cost public utility plant.[3]

Summary

We believe that this Btu system provides a method of equitably subdividing the steam charges to a multiplicity of power services in industrial plants with power generation and/or mechanical drives, and that it provides a method of readily checking and controlling costs. The resulting costs and/or fuel-use rate can readily be compared to other plants. Further, once the system is worked up its use can be routine, provided corrections are made when equipment or other changes are made.

[3] Federal Power Commission Report for Year 1953.



COMBUSTION ENGINEERING ADOPTS YARWAY SEATLESS BLOW-OFF VALVES FOR PACKAGE BOILERS

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YARWAY BLOW-OFF VALVES

Tests of Accuracy of Laboratory Preparation and Analysis of Coal Samples

By R. L. CORYELL* and F. J. SCHWERD*

Consolidated Edison Company of New York, Inc.

This report describes the tests made to determine the accuracy of the sample preparation and analysis, and compares the accuracies thus obtained with the results of other investigators.

DURING the past few years, extensive tests have been made of the accuracy of coal sampling under field conditions. Tests made by this Bureau of our Company's Mechanical Engineering Dept. have included mechanical sampling at East River Station (1),[1] manual sampling at Hudson Avenue Station (2) and manual sampling of coal cars at the New Jersey piers (3). While the primary sampling is the basic operation, it constitutes only one of several steps in obtaining the analysis of the coal. Of equal importance are the preparation of the sample for analysis and finally the analytical operations.

The preparation of the primary coal sample consists of successive reduction in particle size and division of the sample to final laboratory sample of minus 60 mesh sieve size. For this investigation, the sample preparation was performed stepwise as shown in Fig. 1, and the accuracy of each step was determined. Finally, the accuracy of the ash analysis operation was determined. It has been found convenient to express these accuracies in terms of an error that will occur less often than one time in 20. In analyzing test data, we find the term "variance" (mean square of the deviations) very useful since the over-all variance is simply obtained as the sum of the component variances.

To make a variance value readily understandable in terms of the ASTM permissible errors in coal sampling and analysis, the following table is offered:

A Variance of	Represents an Error Not Exceeding
0.01	±0.2 Per Cent
0.09	±0.6 Per Cent
0.25	±1.0 Per Cent
0.49	±1.4 Per Cent

Thus the accuracy required to meet ASTM standards for a 10 per cent ash coal represents a maximum error of ±1.0 per cent or a variance of 0.25.

* Division Engineer and Assistant Engineer, respectively, Mechanical Engineering Dept.

[1] Numbers in parentheses refer to similarly numbered references in the Bibliography at the end of the paper.

Sample Preparation Procedures

Coal samples of 15 to 30 lbs, crushed to minus 4 mesh, are received at the laboratory in 5-gal cans. This coal is immediately riffled to about 5 lbs and air-dried. This 5-lb sample is then crushed to minus 20 mesh in a Sturtevant grinder. This ground sample is mixed on a glazed-surface mixing cloth. After this mixing, two 200-g samples are removed by means of a spoon. One of these 200-g samples is saved for a laboratory reserve sample. The other is pulverized in a ball mill. This pulverized sample is riffled once through a $^1/_4$-in. riffle sampler. The resulting 100-g sample is put through a 60-mesh sieve and the oversize reduced on a bucking board until the entire sample passes the 60-mesh sieve. The total 60-mesh sample is placed in a bottle and mixed on a mixing wheel. After mixing, two 2-oz bottles are filled by means of a spoon. One of these is used for determination of proximate analysis; the other is used for calorimetric analysis. The remainder is burned off for determination of fusibility of ash.

During this special test, the regular laboratory procedure was used except that duplicate samples were prepared as indicated in Fig. 1, from that portion normally discarded at various steps of the preparation. In addition, replicate laboratory samples were prepared from each gross sample. These replicates were prepared and analyzed in the same manner as shown in the flow diagram for the "B" portion of the sample.

Other investigators (4, 5, 6) report the use of from one to three stages of riffling between stages of crushing and pulverizing. Some laboratories pulverize the 4-mesh coal directly to 60 mesh, omitting the 20-mesh stage. In some cases, mechanical sample dividers are used instead of riffles. There appears to be no other investigator using the spoon method for dividing the 20-mesh sample. However, this method is used by all for the removal of the 1-g sample of pulverized coal for chemical analysis.

Test Results

The results of the tests made by this Bureau are appended. The results of statistical analysis of these data and data of other investigators are given in Tables I, II and III. A limited number of experiments were made

Editor's Note: This is the final article of a series on coal sampling by these authors. See October, November issues for the earlier parts.

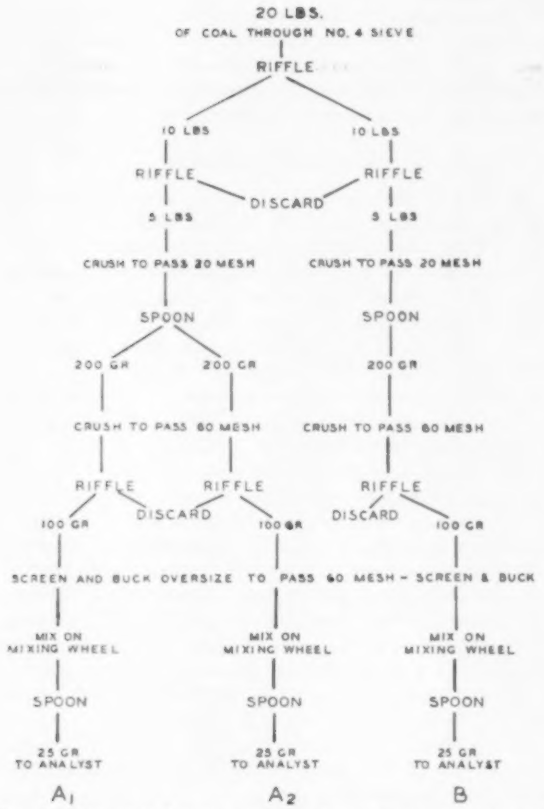

Fig. 1—The step-by-step preparation of the initial coal sample is detailed above and each step's accuracy was determined

to permit separation of the variances at each step of the preparation. Bias has been identified and evaluated.

Table I gives a comparison of the variances of the sample preparation and analysis for a number of recent tests by various investigators. These figures include the effect of bias, if any. These tabulated values do not include the station preparation of the laboratory samples. However, the "laboratory sample" varied in size in the different investigations. The group averages of these samples ranged from 15 to 200 lb., as indicated in the tabulation.

The Cabin Creek samples were reported to be 95 per

TABLE I—VARIANCES OF SAMPLE PREPARATION AND ANALYSIS

	Weight of Sample, Lb	Average Per cent Ash	Total Variance	Number of Samples
Con Edison mixed cargoes, 1952	50	9.5	0.1087	60
Con Edison mixed cargoes, 1953	15–30	10.4	0.1284	30
Con Edison car samples, 1954				
Resultants and sized coals, top size 2 in. or less	20	9.0	0.0568	16
R/M and top sizes over 2 in.	20	8.4	0.1046	14
Cabin Creek Tests (5)				
Lab A	95	10.3	0.007	79
Lab B	95	10.3	0.069	79
Lab C	95	10.6	0.103	79
Lab D	95	10.1	0.029	79
Over-all average	95	10.3	0.0603	79
Enos Coal (6)	15	12.5	0.0501	30
British Tests (4)				
Lab A (using riffles)	50 and 200	9.2	0.072	12
Lab B "	"	8.4	0.054	12
Lab C "	"	6.8	0.073	12
Lab D "	"	8.3	0.052	12
Lab E "	"	7.7	0.010	12
Lab G "	"	6.3	0.018	12
Lab H "	"	4.0	0.010	12
Lab J (using rotary samplers)	"	8.4	0.102	12
Lab K "	"	8.9	0.014	12
Lab L "	"	4.2	0.037	12

cent through No. 8 sieve as compared with the No. 4 sieve used in the Con Edison and Enos tests (6). Some of the British samples were crushed finer than No. 4 sieve (nominal $^3/_{16}$ in., used by BSI).

There is a wide variation in the accuracies reported by different laboratories. Four of the British laboratories and one laboratory in the Cabin Creek tests show exceptionally close agreement between duplicate samples. The results reported in the Con Edison tests on coals under 2 in., in the Enos tests, by one laboratory in the Cabin Creek tests and by four laboratories in the British tests all fall in a mid-range degree of accuracy. Unsatisfactorily high variances were found in the Con Edison tests on mixed coals and coals over 2 in. The results reported by one of the Cabin Creek test laboratories and by one British laboratory showed a similarly poor accuracy.

Table II compares the variances for each stage of sample preparation and analysis of those laboratories which carried out the tests so that it was possible to measure the variance at each step.

In the Con Edison experiments, the greatest difference in the behavior of different classes of coal was found to be in the riffling of the 4-mesh sample (V_1). The mixed cargoes and large-sized coals showed a much higher variation than coals of 2-in. top size or smaller. The improvement in the variance at the 20-mesh stage (V_2) from 1953 to 1954 can be attributed to a change in the method of selecting the 200-g sample. Originally, a spatula was used to "spoon out" the sample to be pul-

TABLE II—ESTIMATED VARIANCES AT DIFFERENT STAGES OF PREPARATION

	Per cent Ash	No. 4 Sieve, V_1	No. 20 Sieve, V_2	No. 60 Sieve, V_3	Total Preparation, ΣV_P	Analysis, V_a	Over-all Variance, VTotal
Con Edison, 1953							
Mixed Cargoes	9.7	0.0641	0.0504	Neg.	0.1145	0.0139	0.1284
Con Edison, 1954							
Sized coals, top size 2 in. or less	9.0	0.0144	0.0306	0.0027	0.0478	0.0091	0.0568
R/M and over 2-in. top size	8.4	0.0657	0.0271	0.0027	0.0955	0.0091	0.1046
Enos Coal	12.5	0.0251	0	0.0225	0.0476	0.0025	0.0501
British Tests							
Clean Coal:							
Lab A	9.2	0.040	0.022	.....	0.062	0.009	0.071
Lab C	6.8	Neg.	0.072	.....	0.072	0.005	0.077
Lab D	8.3	Neg.	0.053	.....	0.053	0.005	0.058
Lab K*	8.9	Neg.	0.011	.....	0.011	0.005	0.016
Lab L*	4.2	0.012	0.022	.....	0.034	0.003	0.037

V_1—Variance of error in sampling 3 to 6 lb from the total 4-mesh sample. (British $^3/_{16}$ in.)
V_2—Variance of error in sampling approximately 200 g from 3 to 6 lb of coal through 20 mesh. (British 14 mesh.)
V_3—Variance of error in sampling approximately 50 g from 200 g of coal through 60 mesh.
V_P—Total variance of error in sampling.
V_a—Variance of the analytical errors, including the error of sampling 1 g from the bottle of 60-mesh coal. (British 72 mesh.)
NOTE: The British omit stage 3. The 1-g sample for analysis is selected from the entire 200-g sample pulverized to 72 mesh without any intermediate reduction of the sample size.

* Using mechanical rotary dividers in place of riffles.

TABLE III—CON EDISON TESTS, 1954

Resultants and Sized Coals, Top Size 2 In. or Less (ASTM GROUPS 1, 2 AND 3)

	Source of Variance	Total Variance	Variance Due to Bias	Variance of Random Error
V_1	4 mesh	0.0144	0.0030	0.0114
V_2	20 mesh	0.0306	...	0.0306
V_3	60 mesh	0.0027	0.0027	...
V_a	Analysis	0.0091	...	0.0091
	TOTAL	0.0568	0.0057	0.0511

Run of Mine and Coals with Top Size Over 2 In.

	Source of Variance	Total Variance	Variance Due to Bias	Variance of Random Error
V_1	4 mesh	0.0657	0.0500	0.0157
V_2	20 mesh	0.0271	...	0.0271
V_3	60 mesh	0.0027	0.0027	...
V_a	Analysis	0.0091	...	0.0091
	TOTAL	0.1046	0.0527	0.0519

TABLE III—Enos Coal Sampling Test (6)
2 × 0 Enos Coal

	Source of Variance	Total Variance	Variance Due to Bias	Variance of Random Error
V_1	4 mesh	0.0251	0.0095	0.0156
V_2	20 mesh	...	...	...
V_3	60 mesh	0.0225	0.0057	0.0168
V_a	Analysis	0.0025	...	0.0025
	TOTAL	0.0501	0.0152	0.0349

verized. This was changed by putting sides on the spatula to prevent spillage while transferring the sample.

Of the data from five British laboratories, the two which used rotary samplers instead of riffles show the lowest variance. Of the three using riffles, the two which ground the coal finest at the first stage of crushing also showed the lowest variance at this stage.

In the case of the Cabin Creek tests (Table I), it was pointed out in the original report (5) that those laboratories using the greatest number of stages of riffling showed the highest variance. Also, those laboratories which crushed the coal finer before further division of the sample obtained better results.

In the case of the Con Edison tests made in 1954 and also in the Enos tests, the design of the experiment permitted isolation of the component of variance due to bias at each stage of preparation. These data are given in Table III. All three sets of data indicate that bias existed. The Con Edison samples of coal with top size of 2 in. or less, which included coals falling into ASTM size groups 1, 2 and 3 (D 492-48), showed the least bias, the Enos 2 × 0 coal evinced a greater bias, and the R/M and over 2-in. top size coals were the worst offenders. In fact, the bias found in the riffling of the 4-mesh samples (V_1) of the over 2-in. and R/M coals accounts for most of the increase in variance.

Discussion of Results

In the Con Edison Company coal sampling tests, the riffling operations generally showed the existence of bias. This was confirmed by other American (5, 6) investigators. The British investigations (4) showed high variance for these operations but with no appreciable bias, possibly due to the testers being on their "best behavior" for the special tests. It is therefore concluded that under routine test conditions a bias is quite apt to be introduced in the riffling operation. The magnitude of this bias appears to increase with coals having the highest inherent variances.

These Con Edison sampling tests and the British investigations showed higher variances in the division of the 20-mesh size samples than in the 4-mesh size samples when bias is excluded. In the Enos coal tests, however, the higher variances occurred in the sample division at the 60-mesh level. There are limited data showing that these variances may be decreased by use of rotary sample dividers rather than riffles. It has also been shown that it is essential to have the samples entirely crushed to pass the 60-mesh sieve before making the final division.

In an effort to improve the accuracy of coal sample preparation in the Chemical Laboratory, the following steps have been taken:

1. Purchase of a "Thermic" rotary sample divider. Delivery was obtained about July 1, 1955. British experience with this sampling device has been very satisfactory on coals crushed to pass 4-mesh sieve.

2. Purchase of a hammer mill coal pulverizer to crush the samples to pass a 60-mesh sieve. This unit

APPENDIX

TABLE A—RESULTS OF TESTS OF LABORATORY PREPARATION AND ANALYSIS

Sample No.	Size of Coal in Shipment	Per Cent Ash by Weight, Replicate Number: I, A_1	I, A_2	I, B	II	III
1	Run of Mine	6.6	6.7	7.3	7.1	6.9
2	Slack	10.8	10.6	10.4	11.1	11.4
3	1 × 0	8.7	9.1	8.5	8.3	8.6
4	Run of Mine	10.1	9.7	11.4	11.3	11.3
5	Slack	10.9	10.6	12.2	10.8	11.1
6	Run of Mine	8.4	8.2	8.4	7.9	8.6
7	1 1/2 × 0	8.1	8.2	8.5	8.0	8.1
8	Slack	7.2	7.1	7.4	7.2	7.3
9	Run of Mine	8.2	8.2	8.4	8.5	8.2
10	2 × 0	7.6	7.7	7.6	7.8	8.4
11	2 1/2 × 0	6.0	6.0	5.9	5.8	5.9*
12	Run of Mine	7.1	7.2	7.6	7.6	7.7
13	1/2 × 3/8	8.4	8.8	8.6	9.0	8.7
14	2 1/2 × 0	9.3	9.9	9.2	9.7	10.6
15	3/4 × 0	11.6	11.2	11.5	11.4	11.1
16	1 × 0	9.5	9.1	9.6	10.0	9.6
17	Run of Mine	8.5	8.6	8.5	9.1	9.3
18	3/4 × 0	10.4	10.1	10.7	10.2	10.9
19	3 × 1 1/2	6.5	6.5	7.3	7.0	7.7
20	Run of Mine	9.2	8.6	9.3	9.4	9.3
21	Run of Mine	11.9	11.7	11.5	11.7	11.2
22	Run of Mine	9.3	9.4	9.5	9.4	9.3
23	2" N&S	8.3	8.3	8.4	8.6	8.6
24	2" N&S	8.2	8.3	8.2	8.1	7.8
25	1 1/4 × 0	7.7	7.3	7.3	7.6	7.5
26	Nut and Slack	9.8	10.2	10.4	10.3	10.3
27	1 1/2 × 0	7.9	7.7	8.4	8.2	8.2
28	2 1/2 × 0	6.2	6.3	5.7	5.8	5.6
29	Run of Mine	7.7	7.4	8.2	7.3	7.7
30	1 × 0	6.7	6.6	6.8	6.7	6.8
	Average	8.56	8.51	8.75	8.70	8.79

* Estimated for purpose of averaging. Sample lost.

TABLE B—ANALYSES OF DUPLICATE PULPS 60-MESH SUBSAMPLES

Sample No.	Per Cent Ash by Weight: Original Pulp	Duplicate Pulp
1	8.99	9.20
2	7.79	7.66
3	8.26	8.10
4	8.71	8.95
5	8.53	8.81
6	9.15	9.50
7	8.55	8.62
8	8.37	8.14
9	9.16	9.06
10	7.28	7.37
11	8.67	8.69
12	8.75	8.79
13	9.39	9.36
14	8.33	8.40
15	9.82	9.99
16	7.72	7.84
17	8.71	8.75
18	8.00	8.21
19	8.91	9.11
20	8.06	8.09
21	10.56	10.86
22	8.58	8.71
23	8.48	8.45
24	9.68	9.73
25	7.80	7.89
26	6.96	6.95
27	8.64	8.77
28	9.80	9.86
29	8.01	8.11
30	8.77	8.80
Total variance		0.0118
Variance due to bias		0.0027
Variance of random error		0.0091

TABLE C—DUPLICATE ANALYSES OF LABORATORY PULPS

Pulp No.	Per cent Ash by Weight — Original Analysis	Per cent Ash by Weight — Duplicate Analysis	Pulp No.	Per cent Ash by Weight — Original Analysis	Per cent Ash by Weight — Duplicate Analysis
1	11.91	11.99	31	7.96	8.17
2	9.77	9.71	32	8.06	8.37
3	10.19	10.25	33	10.31	10.34
4	10.32	10.23	34	8.15	8.18
5	9.15	9.04	35	9.21	9.00
6	8.01	8.10	36	7.22	7.22
7	8.82	8.76	37	7.74	7.66
8	12.70	12.51	38	12.12	12.14
9	8.58	8.56	39	13.28	31.25
10	7.79	7.74	40	8.00	7.91
11	6.90	6.98	41	6.95	6.70
12	8.70	8.85	42	8.13	7.96
13	8.98	9.03	43	8.14	8.33
14	8.64	8.43	44	8.09	8.03
15	10.54	10.68	45	8.15	8.12
16	8.93	9.07	46	8.71	8.77
17	8.95	8.88	47	11.96	11.91
18	8.77	8.83	48	8.69	8.60
19	8.12	7.89	49	7.01	7.03
20	9.02	9.16	50	9.85	10.01
21	8.88	8.97	51	9.62	9.57
22	8.02	8.23	52	9.18	9.17
23	7.77	7.74	53	11.27	11.66
24	7.16	6.94	54	8.85	8.93
25	7.57	7.57	55	8.04	8.07
26	7.66	7.70	56	7.83	7.71
27	6.09	6.15	57	11.70	11.78
28	9.30	9.06	58	6.87	7.01
29	7.14	7.03	59	7.77	7.66
30	8.01	7.88	60	6.91	6.72

Total variance	0.0091
Variance due to bias	0
Variance of random error	0.0092

has been installed in the laboratory for some time now.

Tests will be made of the accuracy of dividing the station samples into 3-lb portions which will be air-dried and pulverized to 60-mesh size. If successful, this procedure will eliminate three steps now being taken in the laboratory preparation of the sample. Since each step may possibly introduce some error, the proposed procedure should increase the over-all accuracy of the coal sampling and analysis.

A further step in simplifying the sample preparation would be the use of a rotary sample divider on the 60-mesh sample. Consideration is now being given to the Sharples' "Powder Sample Splitter," which is not yet in commercial production.

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Stone & Webster Named for New Virginia Electric and Power Company Unit

Virginia Electric and Power Company has just retained Stone & Webster Engineering Corporation to design and construct a new 165,000-kw addition to the Bremo power station at Bremo Bluff, Va., which will bring the station's capability up to 265,000 kw. Cost of the new VEPCO extension is estimated at $22,000,000, with May, 1958, the anticipated date of operation.

The Bremo plant represented an outstanding design at the time it first went into operation in 1931 with two 15,000-kw units. These were later augmented by a 66,000-kw, 1200-psi, 950 F unit installed by Stone & Webster in 1950. Although the original ultimate capacity was anticipated to be 150,000 kw, the new unit will, with its 165,000-kw capability, nearly triple the plant's former capacity. The new unit is the second one of 165,000-kw capacity to be installed by Stone & Webster Engineering Corporation for the Virginia Electric and Power Company system.

Commonwealth Edison Company Installs Third Unit At State Line

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State Line Station provides an unusual opportunity to make a comparison of three large steam turbine units which were placed in operation in 1929, 1937 and 1955. Sargent & Lundy acted as consulting engineers for Unit No. 3, as well as for Unit No. 1 and Unit No. 2. The author points out special features of mechanical design and pays a tribute to the designers of Unit No. 1 which in 1954, after a quarter century of reliable service, turned in an average heat rate performance which was better than the originally expected plant heat rate.

OVER the past decade or so utility engineers and management personnel have been forced by the steadily increasing load to plan for the future without taking sufficient time out to look back and evaluate their past work. It is the purpose of this article to point out some of the unusual items of interest in connection with Unit No. 3, to state some of the reasons back of the design and to make comparisons of the three turbine-generator units located at State Line Station.

In Unit No. 1 we have an installation worthy of review. Under a date line of October 29, 1929, an article in *Power* states, "First 208,000-kw three-element unit of 1,000,000-kw plant is in operation." At that time this was the world's largest steam power unit and it held that record for over 25 years. The fact that it held that record for so many years is convincing proof that it was far ahead of anything else which had been designed and built up to that time. The steam manifold continually conducted steam to one or more of the three elements of this unit from December 1929 to July 1, 1952. Likewise the 22-kv ring bus has never been totally de-energized since the plant was first put into operation in July of 1929. It is felt that tribute is due the engineers and to management for designing and building a plant capable of producing such an excellent record.

The expected plant heat rate for this unit was 13,420 Btu per net kwhr, yet in 1954, after 25 years of reliable service, its average heat rate for the year was 12,966 Btu per net kwhr at a capacity factor of only 57 per cent. This is the best performance it has turned in and shows that a well maintained machine can live up to or better its original capabilities. During the year it carried a wide diversity of loads ranging from 10 to 232 megawatts.

Unit No. 3

Unit No. 3 installed in 1955 is a General Electric 3600–1800-rpm cross-compound, double-flow, 2000-psig, 1050-F primary and 1050-F reheat turbine rated at 221,469-kw at 1 in. back pressure. It is connected to two hydrogen-cooled, 15,500-v, three-phase generators totaling 217,647 kva at $^1/_2$-psig and 272,058 kva at 30-psig hydrogen pressure.

Unit No. 3 is served by a 1,350,000-lb-per-hr Combustion Engineering pulverized-coal-fired, controlled-circulation, dry-bottom, twin-furnace boiler, using eight Raymond bowl mills, three Ljungstrom air heaters, and a Research Corp. mechanical-electrostatic dust collector.

Turbine

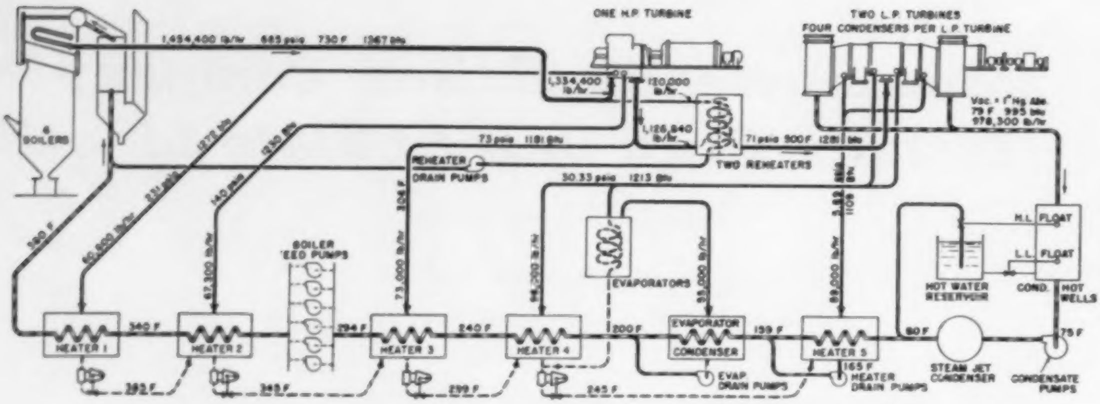
This machine was one of eight almost identical units that were sold at approximately the same time and were put through the shops in assembly line production style. Unit No. 3 is the first turbine-generator built by the General Electric Company using the newly designed 43-in. buckets in the last row. The unusual size and weight of this bucket required special handling throughout its manufacture.

The forgings weighed 211 lb and the finished bucket, ready for pinning to the wheel, weighed 73 lb. It is so designed that, with the exception of the two lacing wires and shroud, any bucket may be removed from the wheel without disturbing any other bucket. The assembled wheel is 14 ft. 7 in. in diameter and contains 130 buckets. A point on the tip travels at the rate of 944 mph. At a maximum steam flow of 1,313,000-lb per hr, the turbine generator will produce:

208,747 kw at 2.5-in. back pressure.
221,469 kw at 1.0-in. back pressure.
225,078 kw at 0.5-in. back pressure.

This results in 16,331 kw more output at 0.5 in. than at 2.5 in. and 3609 kw more at 0.5 in. than at 1.0 in. The industry has for a long time stressed the importance of increased pressures and temperatures but it has neglected the gain in output and better efficiency at the exhaust end of the machine for locations where cold water is available, as exemplified in the preceding.

Table I shows a comparison between the three turbine units installed at this station.



Heat balance—State line Unit No. 1 load on turbine unit—150,000 kw at 1 in. Hg abs

Heat Rate:	
Turbine	9850 Btu/kwhr
Auxiliaries	650 Btu/kwhr
	10,500 Btu/kwhr

Boiler room efficiency, 84 per cent
Operating efficiency ratio, 90 per cent
Station heat rate, Unit No. 1, 13,890 Btu/kwhr

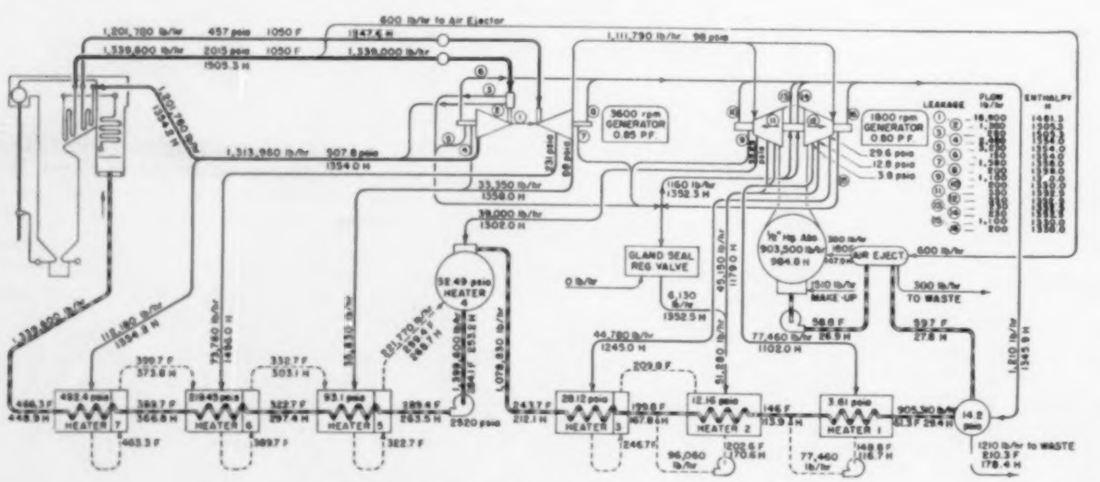
TABLE I—COMPARATIVE TURBINE DATA OF UNITS 1, 2 AND 3

	Unit No. 1*	Unit No. 2*	Unit No. 3†
Start of operation, year	1929	1937	1955
1. Rating (name plate), kw	208,000	150,000	207,000
2. Capability at 1 in. Hg (gross), kw	232,000	164,000	221,469
3. Throttle pressure, psig	675	1,215	2,000
4. Throttle temperature, F	735	840	1,050
5. Reheat temperature, F	500	825	1,050
6. Turbine heat rate at 1 in. back pressure, Btu per kwhr	9,870 (best at 155,000 kw) 10,090 (208,000 kw)	8,470 (best at 126,000 kw) 8,560 (150,000 kw)	7,325 (207,000 kw) 7,310 (221,469 kw also best)
7. Plant heat rate (annual average)	13,180	11,180	9,000
8. House generators	2–4,000 kw	0	0
9. Bleeder stages	5	4	7
10. Feed water temperature to boiler, F	355	420	466

* Actual performance. † Expected performance.

The next two charts show the heat balance for Units 1 and 3, respectively, and the comparison should be of interest to students of the steam cycle.

Unit No. 3 turbine heat rate is 2560 Btu per kwhr or 25.9 per cent better than Unit No. 1. On first thought it may be assumed that turbine efficiencies, or rather blade efficiencies have improved tremendously over the past 26 years. Such is not the case. The blade efficiency has made little or no improvement. The above improvement is due in most part to the steam cycle improvements resulting from the increase in pressure and temperature and the additional bleeding of the turbine for feedwater heating. The above tabulation shows that the design

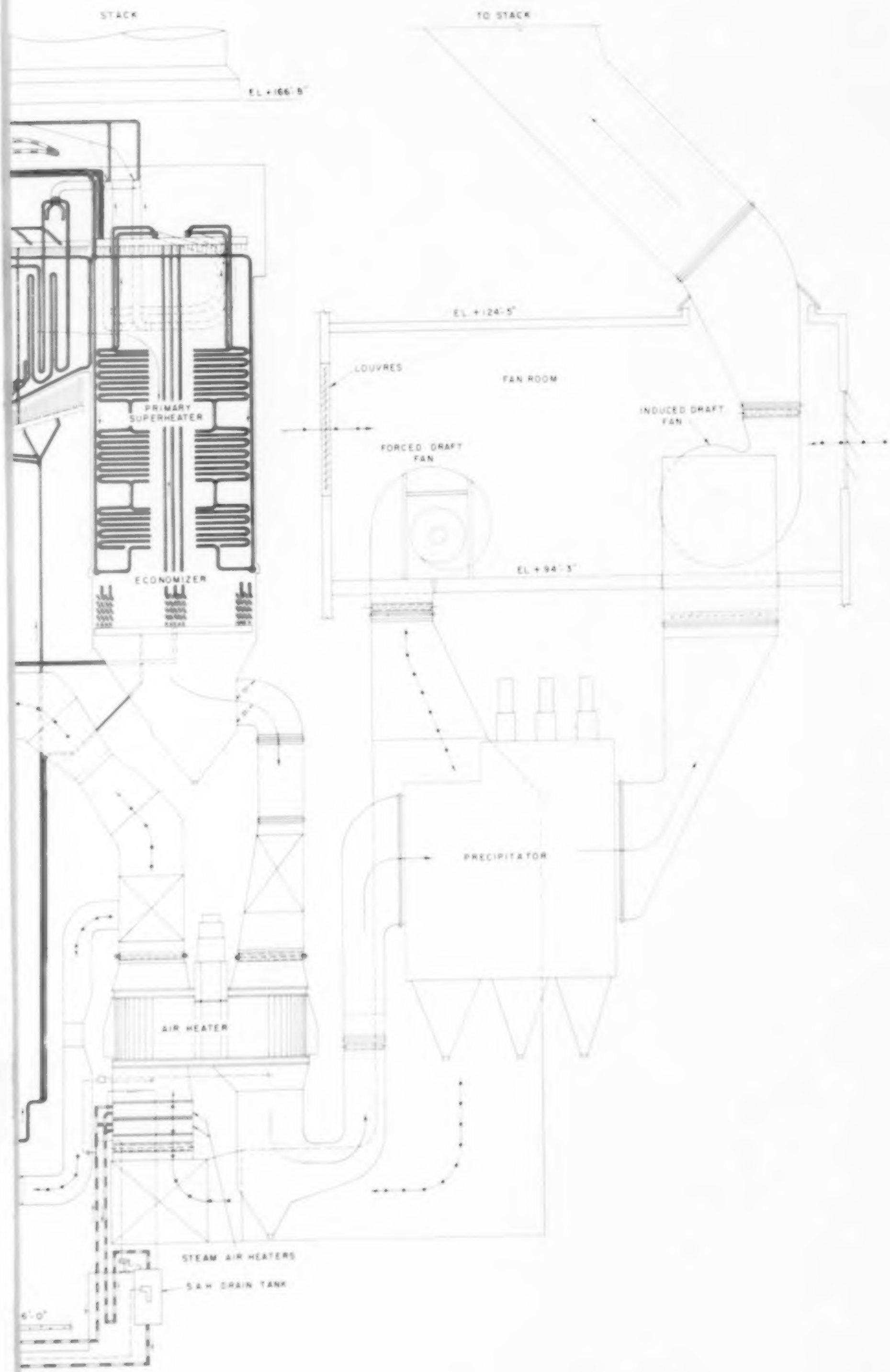


Heat balance—State line Unit No. 3 maximum throttle flow, 1/2 in. Hg abs

Gross generator output, kw	229,697
Auxiliary power at 6.0 per cent	13,782
Net sent out, kw	215,915
Turbine steam rate, lb/kwhr	5.83
Turbine heat rate, Btu/kwhr	7173
Boiler efficiency, per cent	89.26
Btu/kwhr generated	8036

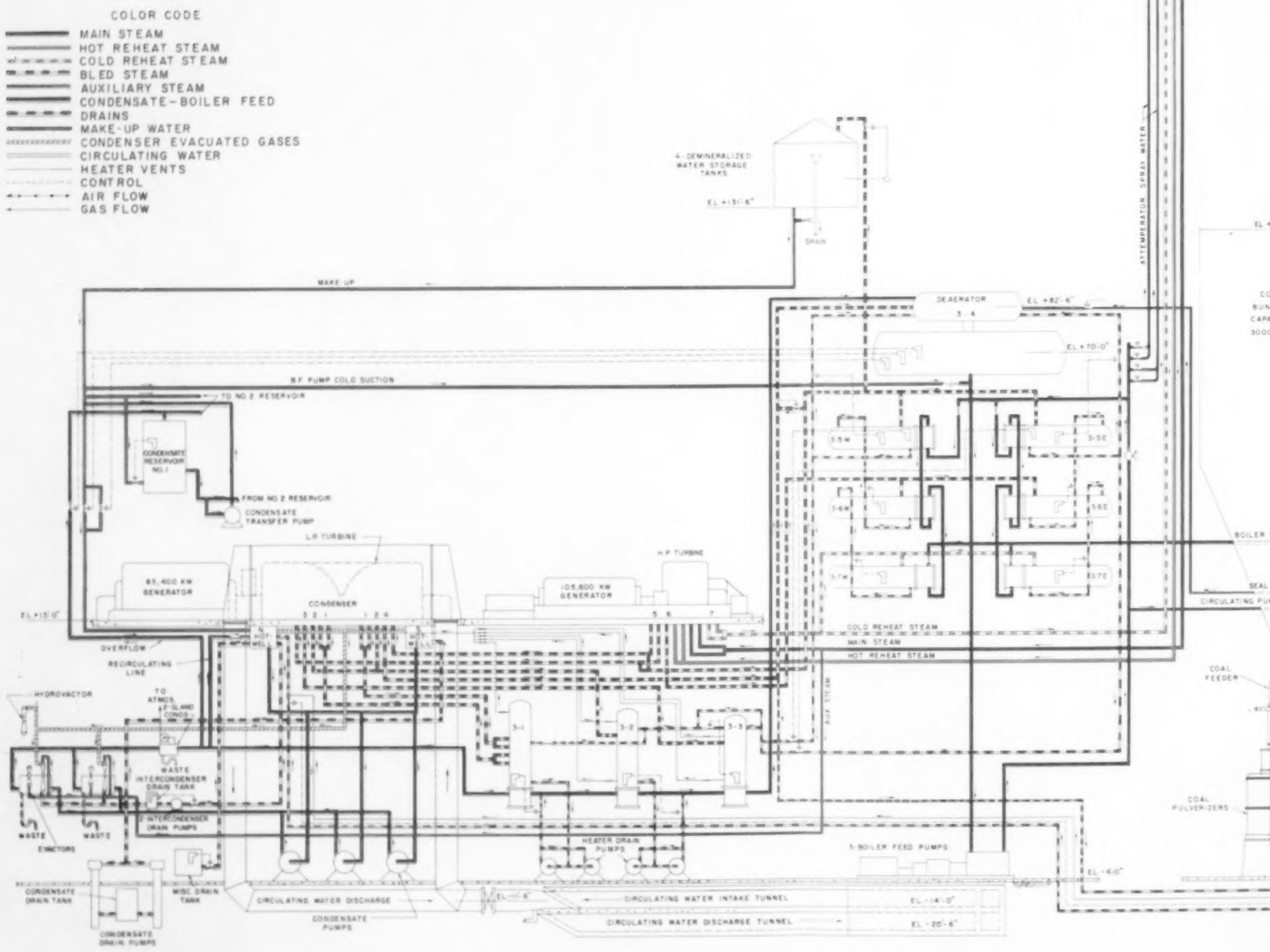
Operating efficiency, per cent	98	99	100
Btu/kwhr sent out	8723	8635	8549
Thermal efficiency, per cent	39.12	39.52	39.92

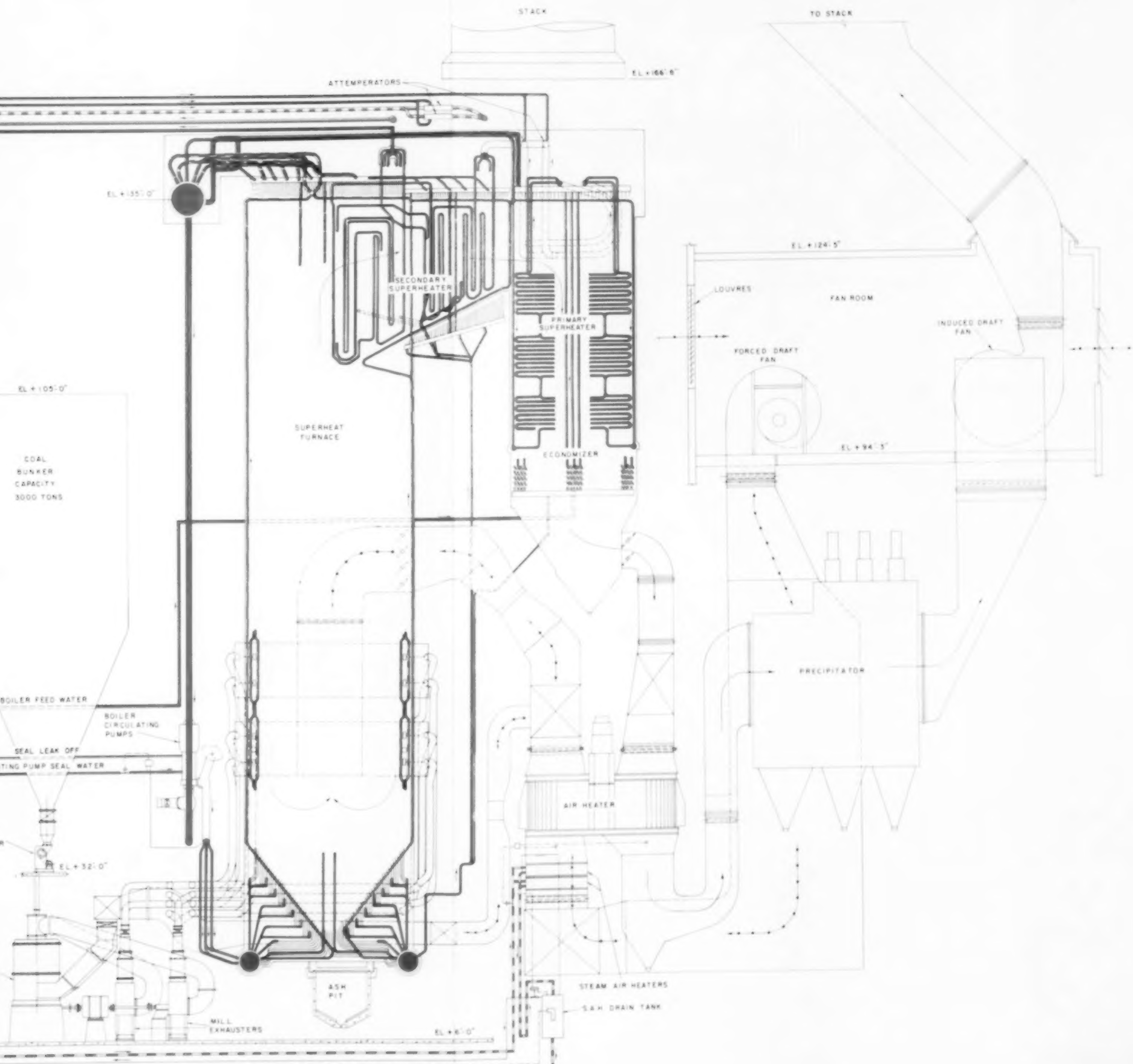
Turbine-generator: nominal 191 mw, cross compound
Boiler: 1,350,000 lb per hr, pulverized-coal-fired
Circulating water circuit: siphon

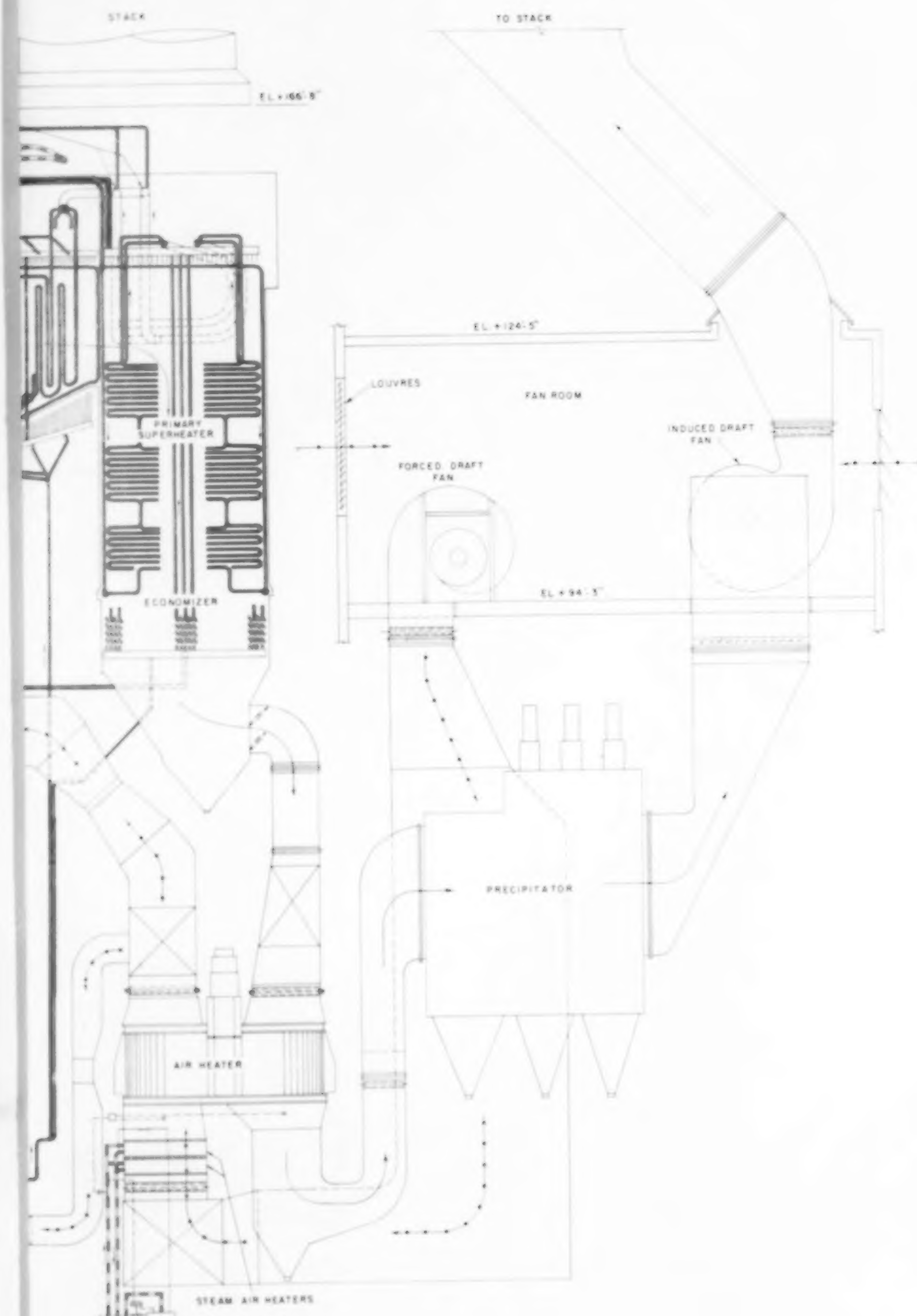


STACK
TO STACK
EL +166'-9"
EL +124'-5"
LOUVRES
FAN ROOM
INDUCED DRAFT FAN
FORCED DRAFT FAN
PRIMARY SUPERHEATER
EL +94'-3"
ECONOMIZER
PRECIPITATOR
AIR HEATER
STEAM AIR HEATERS
S.A.H. DRAIN TANK

SCHEMATIC DIAGRAM ELEVATION
UNIT No. 3
STATE LINE GENERATING STATION




STACK
TO STACK
EL + 166' 6"
ATTEMPERATORS
EL + 135' 0"
SECONDARY SUPERHEATER
PRIMARY SUPERHEATER
EL + 124' 5"
LOUVRES
FAN ROOM
INDUCED DRAFT FAN
FORCED DRAFT FAN
EL + 105' 0"
SUPERHEAT TURNACE
COAL BUNKER CAPACITY 3000 TONS
ECONOMIZER
EL + 94' 5"
PRECIPITATOR
BOILER FEED WATER
BOILER CIRCULATING PUMPS
SEAL LEAK OFF
TING PUMP SEAL WATER
AIR HEATER
EL + 32' 0"
ASH PIT
STEAM AIR HEATERS
S.A.H. DRAIN TANK
MILL EXHAUSTERS
EL + 6' 0"



STACK
EL.+166'-9"
TO STACK
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LOUVRES
FAN ROOM
INDUCED DRAFT FAN
FORCED DRAFT FAN
PRIMARY SUPERHEATER
ECONOMIZER
EL.+94'-3"
PRECIPITATOR
AIR HEATER
STEAM AIR HEATERS
S.A.H. DRAIN TANK

pressure increased 196 per cent; steam temperature increased 43 per cent, reheat temperature increased 110 per cent, and feedwater temperature increased 33 per cent.

Use of Steam Seals

Steam seals on the turbine shaft are not new to the utility industry. Many turbines were so equipped prior to 1920. Since that time, however, there had been a growing tendency toward water seals, and both Units 1 and 2 were so equipped. Heavy maintenance on the gland runners, and turbine vibration occasioned by gland leakage, has convinced some people to return to steam seals. It is noteworthy that with steam seals, Unit No. 3 can be put under approximately 1-in. vacuum while at standstill. It has also been noted that this machine requires only 23,000 lb of steam per hour under full speed and no load conditions.

It has been customary to put the hydrogen supply bottles beneath the generators. On Unit No. 3, recognition has been given to the possible hazards involved so that storage facilities have been provided away from the main building, and the hydrogen piped into the generators.

Boiler

With boilers becoming wider, the problem of supporting, cleaning and controlling the combustion in them becomes increasingly difficult. To help combat these problems a twin furnace was used. Several advantages of the twin furnace are:

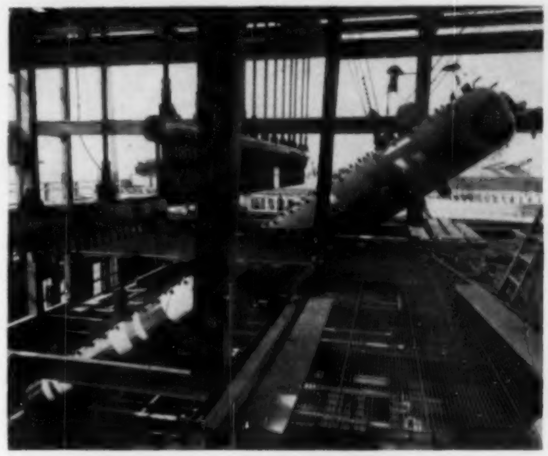
1. Twin-furnace design eased the support problem by permitting the use of a center support column between the furnaces.
2. It eased the problem of obtaining sufficiently long soot blowers to clean across the total width by permitting the installation of shorter units on both sides of each of the twin furnaces. Also, all walls are readily accessible for cleaning.
3. The twin-furnace design permitted the retention of the square shape of the furnace, which is desirable for effective tangential firing.
4. It allowed the installation of reheat surface in one furnace and final section of superheater surface in the other so that by independent and controlled firing between the two units, better control can be obtained for the primary and reheat steam temperatures. This reduces to a minimum the amount of water required for steam temperature control.*

The furnaces are of the all-welded wall design which permitted their erection in panelled sections. This method of construction was carried on in the field with relatively small erection crews, and permitted the joining of these walls in an unusually orderly manner with small welding crews. With this furnace and its controlled circulation, it was possible to place the steam drum in a location that was most advantageous for the station layout. The drum is comparatively small, and its size is determined largely by the quantity of the internals required for the removal of the moisture from the steam. The welded panel wall construction requires that the wall temperatures be kept uniform. This provision is taken care of by controlled circulation pumps.

* The primary steam temperature is controlled by burner tilt between 600,000 lb per hr and 1,240,000 lb. per hr rating. For ratings higher than this automatically controlled desuperheating equipment is installed between the low and high steam temperature stages of the superheater.

Since the reheater furnace is separately fired, the temperature is controlled entirely by burner tilt. A spray type desuperheater is installed in the inlet piping for use in emergencies.

Table II shows the comparison between the boilers on the three units.



Boiler drum for Unit No. 3 being raised into position

TABLE II—COMPARATIVE DESIGN DATA OF BOILERS FOR UNITS 1, 2 AND 3

	Unit No. 1	Unit No. 2	Unit No. 3
Boiler number	6*	3	1
Capacity (lb per hr) (each boiler)	450,000	2—500,000 1—385,000	1,350,000
Pressure, psig at SH outlet	650	1,300	2,100
Number and manufacturer	6—B & W	3—B & W	1—Combustion
Type of bottom	4—dry, 2—wet	Wet	Dry
Feedwater temperature, F	420	420	470
Efficiency of boilers (based on boiler contract)	82.1%	83.7%	89.3%
Exit gas temperature, F	394	326	305
Boiler circulation	Gravity	Gravity	Controlled
Circulating pumps	None	None	4
Capacity of each pump (gpm)			5,450
Burners	Calumet, 8 per boiler	Cross tube, 6 per boiler	Tilting tangential, 32 per boiler
Type of firing	Pulverized coal	Pulverized coal	Pulverized coal
Air heaters	6 tubular	3 tubular	3 regenerative
Heating surface of each, sq ft	56,401	79,750	107,400
Temperature rise, F	451	334	428
Total per turbine unit			
Superheater surface, sq ft	43,200	27,275	147,326
Boiler surface, sq ft	61,764	24,405	0
Economizer surface, sq ft	118,920	77,068	39,800
Air heater surface, sq ft	338,406	239,250	322,200
Reheat surface, sq ft	0	43,100	23,586
Furnace volume, cu ft	123,726	61,920	124,000
Furnace heating surface, sq ft, per furnace	26,489	17,469	46,000

* Only 5 boilers are normally used to carry full load.

HEAT RELEASE DATA**

	Unit No. 1 Boilers			Unit No. 2 Boilers		Unit No. 3
	1 to 4 incl.	5	6	1	2 & 3	1
Heat released Btu per sq ft per hr	94,300	113,100	122,750	106,000	80,800	80,750
Heat released Btu per cu ft per hr	19,530	30,380	24,420	29,961	22,830	14,950
Ratio: Volume, cu ft / Surface, sq ft	4.83	3.72	5.03	3.54	3.54	5.40

** Heat release for Units No. 1 & 2 are for normal daytime ratings. Heat release for Unit No. 3 is based on contract full load rating.

Interior of furnace of Unit No. 3 showing typical panel wall construction

Condenser

Because the operating floor is only 17 ft above the floor of the basement, it was decided to purchase two condensers and locate them alongside the l-p turbine. These Ingersoll-Rand condensers are unique in their design as they are mounted on the same level as the turbine. This necessitates the need for the steam to be admitted to the condensers in a horizontal flow rather than the normal downward flow. The turbine manufacturer had to make a specially designed side outlet exhaust which would evenly divide the exhausting steam from the low pressure turbine into each condenser.

Several other design features were incorporated into the condensers which are as follows:*

1. Appearance: Since the condensers are on the operating floor, special attention was given to attain a pleasing appearance. Their shape as well as the lagging has been designed to give this impression.

2. Tube Pulling: For ease of pulling tubes, the bottom of the tube bundle was placed above the turbine room floor.

3. Air Cooling Section: The air cooling and takeoff section is located at the upper, furthermost corner from the turbine.

4. Support: Each condenser is supported by four adjustable columns. Correct loading on each column is accomplished by hydraulic jacks (1 jack for each column). The condenser casing is bolted solidly to the turbine, but with the columns properly adjusted, there is never any weight on the turbine casing due to the condenser. These jacks play an important role during a turbine overhaul in preventing loading of the turbine casing.

* With all of the design features incorporated into the condenser, the completed condenser was much more successful than had first been anticipated.

Each condenser has a single-pass non-divided cooling-water circuit; that is, each condenser is not split for cleaning and the flow of circulating water is in one direction. By having two condensers, it is possible to open up the water boxes on one of the condensers while there is vacuum on the other condenser and the turbine is operating. Since cutting out one-half of the effective condensing surface will definitely effect turbine operation, condenser cleaning will have to be done at reduced loads.

Table III shows the comparison between the condensers on the three units.

TABLE III—COMPARATIVE DESIGN DATA OF CONDENSERS, FOR UNITS 1, 2 AND 3

	Unit No. 1	Unit No. 2	Unit No. 3
Number	8	2	2
Total area (sq ft)	176,000	90,000	110,000
Sq ft per kw (capability at 1-in. Hg)	0.76	0.55	0.497
Type	Vertical	Vertical	Horizontal
Passes	Single	Single	Single
Number of tubes	38,400	17,900	16,140
Length of tubes (effective)	20 ft	22 ft	29 ft, 9 in.
Diameter of tubes and gage	$^7/_8$ in. OD, 18 ga	$^7/_8$ in. OD, 18 ga	$^7/_8$ in. OD, 18 ga
Total steam load (lb per hr)	1,600,000	850,000	893,000
Steam (lb per hr) per sq ft of area	9.09	9.44	8.12
Heat absorption in Btu per sq ft per hr	8,650	8,950	7,720
Design back pressure (in. Hg)	0.75	1.54	0.89
Design circulating water temp	45 F	75 F	54 F
Total quantity circulating water (gpm)	360,000	180,000	154,000
Water velocity (ft per sec)	6.35	6.81	6.45
Lb of steam per hr per gpm circulating water	4.44	4.72	5.80
Gpm circulating water per kw capability	1.55	1.098	0.695
Water treatment	4—Evaporators	1—Evaporator	Demineralizer

All circulating water pumps on Unit Nos. 1, 2 and 3 are same size: namely, 95,000 gpm.

Building

The building which houses Unit No. 3 was erected in the 1930's. Shortly after its construction, and before Unit No. 2 was completely installed, work was stopped because of the depression. Work was not resumed until some years later so that Unit No. 2 did not go into service until 1937.

Before installation work on Unit No. 3 could start in the turbine room, it was necessary to remove most of the foundation work which had been carried out for a projected 150,000-kw machine which was never installed, and 150 additional timber piles had to be driven for the new foundations. In the boiler room it was necessary to remove the bunkers, most of the steel, and some old foundations which had been erected for the projected boiler installation. It was also necessary to sink fifteen 6 to 9-ft diam caissons approximately 100 ft to bedrock. These old coal bunkers had been used for many years to store fly ash. A bagging plant had been installed at grade level for the fly ash which was loaded into cars or trucks for shipment to be used as a pozzolan in concrete. Practically all concrete on Edison Company construction work for the past 20 years has contained State Line fly ash. Likewise about 130,000 tons of Edison fly ash was used in the Hungry Horse Dam in Montana and 3000 tons in the new Prudential building in Chicago. Other construction projects using fly ash from State Line are the Mackinac Straits Bridge, Kemano Project in Canada and other Bureau of Reclamation Dams. The accompanying illustration shows the new fly ash bagging plant that had to be erected and placed in operation before demolition of the bunkers, etc., could be started.

View of fly ash bagging plant in which pozzolanic material may be loaded into railroad cars or trucks

By placing Unit No. 3, a 207,000-kw single-boiler unit, in the area originally planned for a 150,000-kw three-boiler unit, some rather startling building volume to capability ratios have resulted.

Table IV shows this comparison.

TABLE IV

	Unit 1	Unit 2	Unit 3	Total
Capability (kw) at 1-in. back pressure	232,000	164,000	221,469	617,469
TOTAL VOLUME				
Boiler room (cu ft)	2,890,000	2,034,000	3,060,000	7,984,000
Turbine room (cu ft)	3,870,000	1,307,000	1,320,000	6,497,000
Miscellaneous space* (cu ft)	847,000	662,000	854,000	2,363,000
Total	7,607,000	4,003,000	5,234,000	16,844,000
VOLUME PER KILOWATT				
Boiler room cu ft per kw	12.45	12.4	13.8†	12.9
Turbine room cu ft per kw	16.7	7.96	5.97	10.5
Miscellaneous space* cu ft per kw	3.65	4.04	3.86	3.83
Total cu ft per kw	32.8	24.4	23.63	27.23

* The machine shop, offices, locker rooms, coal handling buildings, gatehouse and construction headquarters and crib house are all included in these figures.

† Since space was available, the dust collectors were installed inside the boiler room on Unit No. 3, whereas they were installed on the roof for Units 1 and 2. This accounts for the larger volume in the boiler room.

Structural Steel

For nearly as far back as one can remember, structural steel erection for power stations has been the bottleneck in keeping the projects on schedule. The riveting crews have been in such limited supply that is is usually necessary for them to work overtime to keep the riveting from lagging too far behind steel erection. Overtime for the riveters always resulted in the entire steel erection force working overtime also. Amounts varying between $30,000 and $100,000 per job have been paid out for overtime on steel erection alone.

By the time Unit No. 3 was authorized, the steel companies had developed the high-tensile (120,000 psi) bolt sufficiently that it was decided to use bolted instead of riveted connections. The cost of the high-tensile bolt material is five times that of the rivets, yet the contract price was the same as a riveted job.

It is believed that the job as a whole cost less and that in the future the bid prices will favor bolted connections over riveted. The two 2-man bolting crews accomplish much more in a given time than the four-man riveting crews. To begin with, bolting does not require skilled labor. The first two-man crew removes the drift pins and the temporary carbon steel bolts and inserts the high tension bolts. A second two-man crew, with the use of a pneumatic impact wrench, tightens the nuts to a predetermined tension. They usually have a number of wrenches which are calibrated daily and set to tighten the nut to a value 15 per cent above the minimum tension required. The bolting was always right up to schedule with the steel erection so that no overtime was required on the job even though it had an exceptionally tight schedule. The construction force was well pleased with the speed with which the steel was erected and permanently bolted, and feel that bolting saved them several months in erection time over riveting.

Stack

The stacks for Units Nos. 1 and 2 boilers were originally 275 ft above grade. They were later extended another 25 ft to reduce the amount of downwash of the gas plume. The company has conducted a number of wind tunnel tests for other units and by extrapolation it was concluded that this new stack should be 400 ft above grade. It is 24 ft in diam at the base and sits on the roof which is 160 ft above grade.

Coal Bunker

The coal bunker has a capacity of 3000 tons or a 32-hr supply at full boiler rating. To reduce the coal dust problem, the bunker is covered and the coal tripper slots are sealed with rubber belting. The bunker then is kept under a slight negative pressure by using an American Filter Corp. Roto-clone which separates the dust from the air, returning the dust to the bunker. This fan also removes coal gases, thus reducing the explosion hazard. Since the fire hazard is of prime importance in the design of coal bunkers, several design features were incorporated into this bunker. These are:

1. The lower portion of the bunker is divided into 4 compartments to permit periodic cleaning out of the old coal without a complete shutdown.
2. The bunker is lined with 25 in. of gunite, which is trowelled smooth in an attempt to keep the coal moving uniformly downward, thus eliminating the accumulation of coal on the bunker walls.
3. CO_2 nozzles have been installed on each of the eight hoppers to smother a possible bunker fire in case of a sudden boiler outage over a long period of time.
4. A cleanout cage operated from a trolley has been provided to lower a man into the bunker when it becomes necessary to clean out the coal.

Compacted Coal Storage

When Unit No. 1 was installed a drag scraper was employed for stock piling and recovering coal that was stored under water. At that time it was considered a very excellent plan to store coal under water and especially the lower grades of coal because of their tendency to fire spontaneously. This underwater storage did not prove successful, partly because the facilities provided were inadequate and partly because the reclaimed coal was too wet to burn, since there were in-

sufficient drying facilities for removing the excess moisture.

The bulk of coal (480,000 tons) is now being stored in one large compacted pile. The station still has 120,000 tons of loose storage which can be reclaimed by a locomotive crane. Compacting coal has successfully overcome the tendency towards spontaneous combustion.

Boiler Feed Pumps

At the time Unit No. 1 was installed the centrifugal boiler feed pump was just starting its development for the higher feedwater pressures and temperatures. Its efficiency was approximately 50 per cent when measured from the motor input to the discharge of the pump. Because of (1) this low efficiency, (2) vibration troubles due to inadequate design, and (3) cutting between stages, consulting and power generating engineers sought a better pump. For Unit No. 2 this thinking led to the purchase of a large 3000-gpm five-cylinder reciprocating pump driven by an a-c, d-c variable-speed 2500-hp Rossman-designed motor through a 12-1 reduction gear. The efficiency of this pump and drive when operating at full load was approximately 90 per cent. Though highly efficient, this pump encountered sufficient trouble with plunger packing and created such violent pulsations on the piping system at each discharge of the five cylinders that, with the large space requirements and the very large increase in investment, no one was willing to spend more time and money in its further development. To reduce the vibration and packing problems, it is now quite successfully operated at little more than half capacity. This is probably the only five-piston reciprocating pump in a large central station anywhere in the world. Two split-case pumps with a 58 per cent efficiency of driver and pump combination using steel casings were installed on the same header with this pump. Because of corrosion-erosion problems, these pumps developed a considerable amount of trouble and were rebuilt. At the higher pressures and temperatures the manufacturer resorted to chrome-steel trim to eliminate the excessive cutting between stages. Since then the successful development of the barrel type pump has eliminated the problems of interstage cutting that were originally so prevalent with the split-case pump.

Unit No. 3 has three identical Ingersoll-Rand centrifugal pumps using the barrel casing. Each pump is connected through an American Blower Gyrol Fluid Drive to a 2500-hp, 3580-rpm, 4000-v Elliot squirrel-cage induction motor. The pumps have an overall efficiency of driver, coupling, etc., of approximately 76 per cent and are rated at 750,000 lb per hr (1620 gpm). Two of these pumps will handle sufficient water to take care of a 10 per cent overload on the boiler.

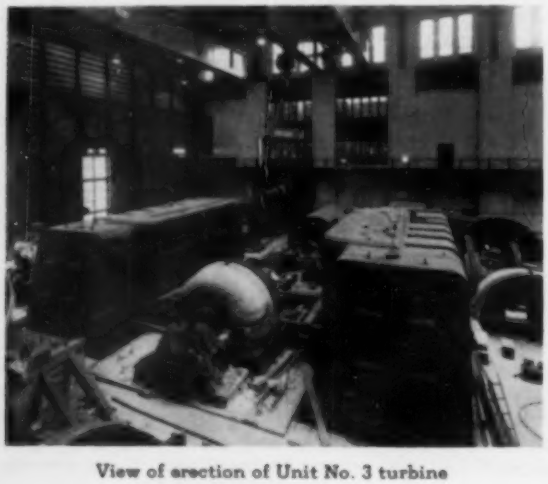
To prevent overheating of the pumps at light loads, a three-inch recirculating line takes water from the discharge and returns it to the deaerating heater. A minimum flow of 135,000 lb per hr is automatically maintained through a modulating recirculating water control valve. Until comparatively recently, recirculation for pump cooling was obtained by either manually or automatically opening the recirculating valve wide open when the flow from the pump reached the minimum. The minimum flow was then obtained by discharging the water through a properly sized baffle breakdown device. This created rather violent surges, so in comparison, the smooth operation of the modulating valve is definitely more desirable.

Dust Collectors

The boiler is equipped with a Research-Cottrell mechanical-electrostatic combination dust collector. Many combination dust collectors have been installed in the East where the sulfur content of the ash is lower and where the dust is drier. Due to the possibility of plugging in the mechanical section, Commonwealth Edison has previously installed straight electrostatic collectors. This is the first combination dust collector on the system. Since the collector is installed in the boiler room it is equipped with an Askarel-filled transformer to eliminate the possible fire hazard.

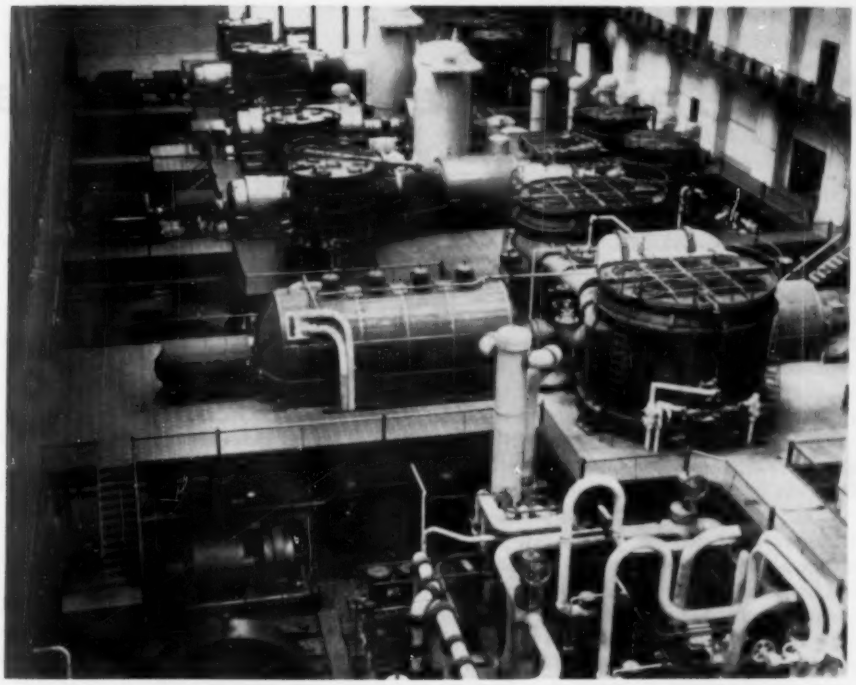
The rectifying equipment on the older dust collectors has been mechanical. Since the life of the vacuum-tube rectifier has improved considerably in the last few years and requires far less operating and maintenance labor than the mechanical rectifier, many of the newer units are equipped with vacuum-tube rectifiers. The collecting plates are cleaned with magnetic impulse rappers and the high-tension electrodes are cleaned with syntron vibrators.

Instead of running high-tension cables from some remote rectifier room, the transformers and rectifiers are



View of erection of Unit No. 3 turbine

Turbine room looking southwest toward Unit No. 2 prior to installation of Unit No. 3



View of turbine room showing 3000-gpm five-cylinder reciprocating pump on lower elevation in foreground, Unit No. 2 turbine and condenser, with Unit No. 1 turbine and condenser in background

installed in compact metal cubicles which are mounted on the dust collector and they in turn are connected to the high tension electrodes through bus ducts.

The color diagram insert is schematic but to a large extent shows the correct physical relationship of the equipment in the station.

Combustion Air Requirements

As units have increased in size, combustion air requirements have created greater air infiltration into the building, with a correspondingly increased discomfort to the operators.

To overcome this, air for combustion is taken from the fan room and louvers are so arranged that air can be taken from out of doors during the winter months and from indoors to aid in ventilation during the summer months.

During the cold weather, the air taken from out of doors requires preheating to keep the metal temperature of the air heater above the dew point of the gas. If this is not done, excessive corrosion and plugging with fly ash occurs. To keep the metal temperature of the air heaters above the dew point, steam is bled from the turbine to the steam air preheaters, located immediately below the air heaters.

Circulating Water Pumps

The circulating water pumps for Unit No. 3 are located in the crib house which also houses the circulating water pumps for the other two units. The pumps for Units Nos. 2 and 3 discharge into a common intake header and the condensers of the two units likewise discharge into a common discharge tunnel.

As condensers have increased in size, the suction head on the hot well has decreased. To improve this situation and still not build the expensive hot well pits of former years, utilities have been purchasing vertical hot well pumps in recent years and installing them below grade.

With this condenser located in the operating floor, it was not necessary to resort to the vertical pumps. Unit No. 3 has three horizontal pumps.

Raising truss for coal conveyor for Unit No. 3

ASME Annual Meeting in Review

ONCE again the American Society of Mechanical Engineers followed the pattern of the last few years and ran its 1955 Annual Meeting in three different locales within the same city. This time it was the Conrad Hilton, the Sheraton Blackstone and the Congress Hotels in Chicago, November 13–18, 1955, for the Society's Diamond Jubilee celebration. Individual sessions seemed, in our experience extremely well attended although total registration, 5000 as against last year's 7500, was down. The abstracts of the many technical papers (better than 300 in all) that bear upon the power field are presented in the following papers and any additional shall appear in the January issue of COMBUSTION.

Joseph W. Barker, right in the photo below, was installed as the newly elected president of the Society, now 40,000 members strong. Mr. Barker, president and chairman of the Research Corp., a former head of the Lehigh University electrical engineering department and dean of engineering at Columbia University for 13 years, is pictured receiving congratulations from the outgoing president, David W. R. Morgan, at the Banquet session of the annual meeting.

Mr. Morgan gave the main talk at the President's Luncheon on Monday, the first full day of the meeting. At that time the five retiring vice-presidents of the Society were in attendance and their photograph appears on this page.

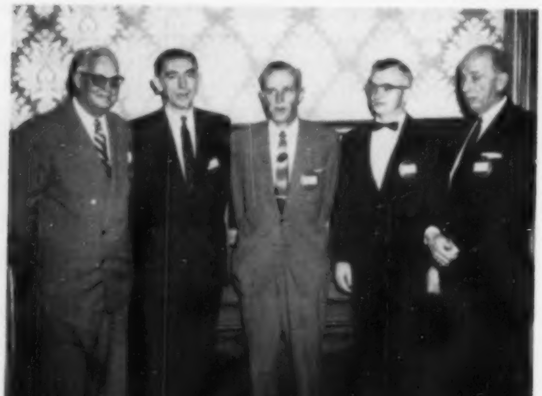
Outgoing president of the ASME, David W. R. Morgan, left, extends congratulations to his successor, Joseph W. Barker at the annual meeting

Seven men were granted honorary memberships. They were Joseph Bradley Armitage, vice president, Kearney & Trecker Corp., James H. Doolittle, vice president, Shell Oil Co., Samuel Broadus Earle, dean of the School of Engineering, Clemson College, Simes Thurston Hoyt, consulting engineer, Castle & Cooke, Ltd., Carl George Arthur Rosen, consulting engineer, Caterpillar Tractor Co., Phillip Sporn, president, American Gas & Electric Co., Clyde Elmer Williams, president, Battelle Memorial Institute.

Mr. Sporn was also awarded the John Fritz medal "for notable scientific or industrial achievement." His career with the American Gas & Electric Co. began in 1920. He became chief engineer of that company and its subsidiaries in 1933 and president in 1947. In 1952 he was elected president of the newly-formed Ohio Valley Electric Corp. Much of his recent work has been devoted to the study of nuclear energy and its application in the field of power generation and because of this experience his comments at presentation were most interesting:

"Considering the large amount of research and development remaining before atomic power plants can be economically competitive realities, only a small fraction of the 100 million or so kilowatts of new generating capacity that will have to be brought into being in the next ten years can be nuclear. For the rest we can and must rely upon conventional sources. If these sources are to be available without imposing excessive strains on our material and human resources then it is necessary that the technology underlying the conventional power supply that we will have to build in the next twenty years be further expanded and improved.

"During the two decades following 1965 the percentage of nuclear power can be expected to increase materially over the preceding year's installations. Even so, it is likely in this country that a large part, if not the majority, of the energy used will still be supplied by equipment and processes utilizing existing techniques or refinements of them. Hence, it will be a long time before we can afford to let up in efforts to improve our present power technology. This has a great record; it has played a key part in bringing our economic system to its advanced state. We dare not neglect it any more than we dare neglect atomic power."



Five retiring vice-presidents, reading from left to right, Thompson Chandler, Dr. Jess Davis, Vernon Peterson, William McLean, W. F. Thompson, are pictured prior to attending the President's Luncheon

Walker W. Cisler, president and director of the Detroit Edison Co., was the 24th recipient of the Henry Laurence Gantt Gold Medal, a joint award of the ASME and the American Management Association "for distinguished achievement in industrial management as a service to the community." Mr. Cisler joined the Public Service Electric and Gas Co. soon after graduation from Cornell University in 1922 as a mechanical engineer. In 1943 he went over to Detroit Edison Co. as chief engineer of power plants, was elected executive vice president in 1948 and president in 1951. As a power executive Mr. Cisler has been responsible for a long-range system expansion program and has played a leading part in atomic energy development for industrial and civilian purposes.

At the presentation ceremony Mr. Cisler expressed the belief that there were four channels of development with which management must be concerned before the potential atomic energy resources can be developed into useful energy. These areas are: technology and engineering, economic and commercial considerations, legal and governmental, organizational and management considerations. On the economic considerations Mr. Cisler felt: "In considering the use of atomic fuels for the production of electric power, we must remember that this substitution can be justified only when the cost of the power produced using atomic fuels is no greater than the cost of power produced in the conventional manner."

Philo Supercritical Pressure Unit

ONE of the highlights of the ASME Diamond Jubilee Annual Meeting was the presentation of three papers describing essential features of the 125-mw supercritical pressure unit now being installed at the Philo Plant of the Ohio Power Co., a member of the American Gas and Electric System. **Phillip Sporn,** president of the American Gas and Electric Service Corp., presided at the three-paper session and at the extended discussion that followed.

The opening paper, entitled "First Commercial Supercritical Pressure Steam-Electric Generating Unit for Philo Plant" was presented by **S. N. Fiala,** chief engineer of American Gas & Electric Service Corp. In the design of the Philo unit, he stated, it was desired to use the maximum combination of temperature and pressure justifiable, since the basic premise of the project was the close relation and interdependence of the two. An operating pressure of 4500 psi was then selected not only because of its apparent optimum relation to 1150 F but also because it gives operating pressures in the feedwater-heater lines, boiler, and steam lines which are within the limits of presently established codes.

The Philo steam generator, designed and built by Babcock & Wilcox, is rated at 675,000 lb per hr at 4500 psi and 1150 F with a feedwater temperature of 525 F. There are two reheat sections; the first will raise 655,000 lb per hr at 1225 psi from 800 F to 1050 F; the second will raise 520,000 lb per hr at 185 psi from 630 F to 1000 F. The unit has an estimated capability of 740,000 lb per hr at the main steam conditions.

The arrangement of the steam generator consists of cyclone-fired furnaces in front of pendant superheaters and reheaters. The walls of the cyclones and the front wall of the primary furnace are cooled by incoming feedwater. The transition from water to steam occurs in the primary superheater in the coolest gas zone. The remainder of the wall and pendant surface is superheater surface. The final superheater is arranged across the width of the furnace. The convection pass is divided by a baffle with the primary superheater on one side and the two reheat sections in series on the other. Gas flow is proportioned by dampers at the outlet of each side. By control of firing rate, main steam temperature will be controlled and by positioning these dampers, one of the two reheat temperatures will be controlled.

To avoid slagging conditions in the pendant and convection sections, flue-gas recirculation is employed to limit gas temperature. Flue gas taken from the convection-pass outlet at 800 F is mixed with hot gas at 3000 F from the primary furnace to reduce gas temperatures entering the pendant sections to 1900 F, which is below the ash-fusion temperature. The steam generator is equipped with a tubular-type air heater. Based on experience at the Philo Plant and elsewhere, the cold-end section of this air heater will be equipped with Corten tubes, because of their greater resistance to corrosive attack from the sulfur compounds present in the flue gas of the high-sulfur coal burned at Philo. Experience indicates that the life of Corten is about two to two-and-one half times that of mild steel.

The General Electric 3600-rpm, tandem-compound, double-flow turbine is rated 125,000 kw at initial steam flow of 675,000 lb per hr at 1150 F and 4500 psi. At full load, steam is expanded from these initial conditions to 1225 psi and 800 F in a double-shell high-pressure turbine. The steam is then reheated in the boiler to 1050 F and expanded through the first reheat turbine to an exhaust condition of 185 psi and 630 F. The steam is again reheated, this time to 1000 F, and then passed through the second reheat turbine and the double-flow low-pressure turbine. The double-flow turbine is equipped with 26-in. long buckets in the last stage.

In attempting to keep dissolved solids to an absolute minimum, all leakage into the cycle must be eliminated in so far as possible. The most likely source of this contamination is the condenser. As a result, condenser design is directed at obtaining the maximum possible freedom from seepage leaks. Among other arrangements, sprayed-rubber coatings are to be applied to the tube sheets to seal off the rolled tube ends. 70–30 cupronickel tubes were selected as suitable to withstand the high pH conditions on the steam side and the conditions met on the circulating-water side so as to minimize tube failures. Similarly, feedwater-heater tubes will be, for the most part, fabricated of 70–30 cupronickel.

A multipurpose demineralizer with a capacity of 100,000 lb per hr is provided. This can be operated either continuously, bypassing about 20 per cent of the condensate to maintain solids at a minimum or, during startup or shutdown of the steam generator, to remove any solids which might wash out during these transient conditions. This latter condition of startup and shutdown governs the capacity of the demineralizer. Although condensate from the old section of the plant will be employed as make-up to this unit, it is planned that this water will be "polished" by the demineralizer before use. In addition filters will be included to operate with the demineralizer or singly, for bypassing condensate during normal operation or during startup or shutdown. It has been estab-

lished that filtration can effectively remove appreciable quantities of iron oxide even at low concentration levels.

An external recirculating system is required with a once-through-type boiler to replace the natural circulation which exists in a conventional boiler even during start-up. Condensate, hot water and later steam must be disposed of until the steam at the superheater outlet is at a condition suitable for starting the main turbine. To protect cyclone and furnace-wall tubes Philo adopted the basic operating maxim of not firing unless at least 225,000 lb per hr of water is circulating. This was based upon a minimum water velocity of 7 fps through the cyclone tubes. Interlocks have been provided to shut off all fires if flow should at any time drop below this minimum amount.

The recirculation system is one of the major points of difference between a conventional boiler and the once-through-type boiler. The design of this system represented one of the most challenging problems associated with the design of the unit as a whole. All equipment must be designed for completely tight shut off against full pressure and temperature conditions. In operation, the piping and valves must withstand pressure drops from 4500 psi down to 150 psi at all temperatures between room temperature and 1150 F. In starting up and in passing through this spectrum of temperatures, the valves must pass first a waterlike phase, later steam which flashes wet and then dry again, and finally completely superheated steam. This imposes particularly severe service on these valves.

W. H. Rowand and **A. M. Frendberg** of the Babcock & Wilcox Co., presented the second paper entitled "First Commercial Supercritical Pressure Steam Generator for Philo Plant." In discussing design consideration the authors stated that of the 985 Btu added to each pound of the fluid in the high-pressure part of this unit, approximately 235 Btu are added to raise the feedwater from 525 F to the critical temperature, 705 F, and approximately 750 Btu are added to superheat the steam above this point. This compares to approximately 705 Btu to generate steam and 370 Btu to superheat the steam in a 2000-psi, 1050 F cycle with 450 F feedwater.

With this relatively small amount of heat to be added to the fluid as water, there comes the choice of arranging the circuits either so some of this heat is absorbed by the water in economizer surface or so all of it is absorbed by the water in furnace high-heat-input area. The latter condition was chosen because it gives some relief in the alloy requirements for the furnace tubes. However, it leaves the problem of getting surface equivalent to economizer surface with low enough receiving temperature efficiently to cool the gas below 800 F entering the air heater.

To accomplish this the primary superheater with a fluid-inlet temperature of 700 F is located on one side of the rear part of the convection pass with the low-pressure reheater having an inlet steam temperature of 630 F on the other side.

Design of supercritical pressure units is made more difficult because of the meager amount of published heat transfer data for supercritical conditions. The authors pointed out that very limited data had previously been obtained above the critical pressure but with steam flowing in an annular space and at much lower Reynolds numbers than used in the universal pressure steam generator. Therefore, an electrically heated test section was installed at the discharge of the pilot unit where fluid could be supplied at temperatures from 220 to 1000 F at pressures up to 5000 psi in order to secure heat-transfer data for use in the design of the Philo unit. This test section consisted of a horizontal 6-ft-long section of Type 304 tubing, 0.300 in. ID and 0.540 in. OD. Thermocouple wells were installed at each end of the tube and a pressure gage connected to a point slightly upstream of the test section. Power was applied to the tube from three 40-kva transformers.

Data were obtained at various flow rates, temperatures and pressures at heat fluxes from 150,000 to 600,000 Btu per sq ft per hr based on inside diameter of the tube. Film conductances proved to be higher than those based on a McAdams correlation particularly in the temperature range of 800 F to 1000 F. The Philo unit was designed on the basis of the McAdams correlation, leaving the difference between this and the test data as "safety factor."

In a paper entitled "First Commercial Supercritical Pressure Steam Turbine Generator for the Philo Plant" **C. W. Elston** and **R. Sheppard** of the Large Steam Turbine Department of the General Electric Co. stated that the basic approach from the designer's point of view has been to consider the Philo turbine as a large developmental unit. In some instances, maximum rotor temperature for example, conditions more severe than necessary were accepted in order to obtain engineering knowledge applicable to even further advances in the future. Operation of this prototype turbine will provide experience with new approaches to the problems of higher pressures and temperatures.

The authors described the steam flow through the turbine in the following terms.

(*a*) Steam cooling—accomplished by surrounding all austenitic parts inside the turbine with a thin thermal insulating metallic liner and circulating cooling steam at almost full pressure between this liner and the more massive ferritic sections which are maintained at lower temperature and which carry the main portion of the pressure load. The resulting small pressure load allows the use of thin-walled austenitic nozzle boxes and steam inlets with low-temperature gradients and reduced susceptibility to distortion.

(*b*) Individual control valve bodies of small diameter and consequently thinner walls.

(*c*) Multiple steam pipes—the number of main steam pipes from the boiler is increased to four with individual turbine stop valves placed in each line permitting small valve bodies and pipe of reduced wall thickness.

(*d*) Simple throttling control with full 360-degree arc admission to the first stage nozzle.

Steam from the boiler reaches the turbine through four separate main steam pipes. Each main steam line has a separate stop valve and a separate control valve located external to the turbine and just below the turbine room floor. The four control valves are operated by their individual operating cylinders under the control of a conventional starting handwheel and speed governor, and an initial pressure regulator.

When starting the cold boiler, the stop valves are closed. The boiler feedpump builds up full water pres-

sure against the closed stop valves, and one or more of the multiple-pressure reducing valves are opened so as to throttle 4500 lb water in the amount of about 225,000 lb per hr to the deaerator. Fire is established in the boiler, the temperature is slowly raised, and the pressure reducing valves are gradually opened by means of a pressure regulator so as to maintain substantially constant flow through the boiler and recirculating system. The steam is desuperheated after throttling through the reducing valves before entering the deaerator. The pressure reducing valves must handle the 225,000 lb per hr recirculation flow from conditions of 60 F water to as high as 1150 F superheated steam. When the temperature of the steam reaches about 900 F, the main stop valves are opened, and the turbine is made ready to roll.

For shell cooling only, approximately 60,000 lb per hr of steam at full load is metered through orifices at the four main steam inlet flanges and is desuperheated under control of a temperature sensing element so as to supply steam at 960 F through four entry points at the inlet flanges to the high-pressure section. With rotor cooling, the system is modified and the total cooling steam flow is increased to 100,000 lb per hr by enlarging the orifices. Leakage control is employed at both the admission and discharge sides of the buckets to minimize the mixing of rotor cooling steam with the main flow in the steam path.

Discussion

C. C. Whelchel of Pacific Gas & Electric Co. pointed out that the relatively large pressure drop across the steam generator removes danger of stagnation of circulation and overheating of tubes. This should increase rates of heat transfer and ultimately result in a reduction in boiler size for a given output.

In discussing the paper by W. H. Rowand and A. M. Frendberg, **A. T. Hunter** of Combustion Engineering, Inc., complimented the authors and added that the continuing study and investigation appears to parallel much of the work being carried on in connection with the commercial application of the once-through boiler in four other utility systems. The Philo unit is scheduled to operate early in 1956, and it will be followed by the 150,000-kw once-through unit for Dayton Power & Light in late 1957, and that for Metropolitan Edison of 175,000-kw capacity early in 1958. The large supercritical pressure units for Cleveland Electric and Philadelphia Electric, of 250,000 and 325,000-kw capacity, respectively, are scheduled for operation in late 1958. By 1960, then, a comprehensive operating background of over 1,000,000 kw will be available to support the general commercial acceptance of these advances at that time.

Indications would point to a prediction that the bulk of utility capacity purchased as early as five years from now will be in sizes ranging from 200,000 to 400,000-kw capacity. In these large sizes, the overall gains to be obtained in the use of supercritical pressure are significant, and it is believed that at that time will be clearly justified from an economic standpoint. The relatively low supercritical pressure of 3500 psig at the present generally accepted moderate temperature of 1050 F for primary and reheat steam appears at particular advantage in this connection. This cycle will by then, it is believed, have found a solid place in technical and economic thinking. By 1960, the improvement in alloys and the techniques in handling them with the anticipated reduction in their cost could lead as well to the general use of the superpressure higher temperature cycles, with double reheat in the very large sizes.

G. E. Klapper of Philadelphia Electric Co. stated that the designers of the Eddystone supercritical unit were faced with some of the same departures from conventional practice and independently used approximately the same approach as did the Philo designers. He added that the starting up and shutting down procedures would be similar in both cases.

In closing the session Mr. Sporn observed that the papers presented were the results of 30 months of intensive engineering research and development. He looked upon the Philo project as a necessary step in demonstrating the feasibility of breaking through the pressure barrier and expressed confidence that it would turn out to be a great success.

Turbine Materials Failure

A six-paper symposium was presented under the auspices of the Power and Metals Engineering Divisions on the subject of materials failure in rotors of large steam turbine-generators. The symposium was occasioned by the concern of both manufacturers and users to prevent, if at all possible, future mishaps of the type that took place in 1953 and 1954. The papers revealed a high degree of cooperation among turbine manufacturers, suppliers of rotor forgings, independent consultants, and power companies in investigating causes of the accidents, reconstructing these causes through metallurgical analysis and model testing, and in taking steps to improve inspection techniques to minimize material defects contributing to rotor failure. The papers evoked considerable discussion which provided further evidence of the openness with which the investigations were carried out and the desire of all concerned to make certain that future mishaps will be avoided.

Failure at Tanners Creek

The first of the papers which was prepared by **A. W. Rankin** and **B. R. Seguin** of the General Electric Co., set forth the results of an investigation into the causes of the turbine wheel fracture which took place early in January 1953 on the 1800-rpm low-pressure element of Unit No. 1 at the Tanners Creek Station on the American Gas and Electric system. The front standard, which contains the No. 1 bearing, the thrust bearing, hydraulic cylinder, and governing mechanism—cracked, and the resulting oil leakage caused a fire within the station. When the turbine was opened for inspection, it was found that a segment of approximately 160 deg had broken out of the first-stage (reheat) wheel of the intermediate-pressure turbine section.

A review of the results of all the investigations conducted on this turbine rotor indicate that the most probable cause of this fracture was a combination of residual stresses which were not removed by the tempering and stress-relief heat treatments, an unusually low long-time, high-temperature ductility, and thermal stressing of the first-stage wheel due to admission into the first-stage wheel space of wet steam from the steam-seal regulator piping. Improved practices have been introduced to avoid the recurrence of difficulties due to any of these contributing causes: specifically, residual stresses

are now measured on all rotor forgings prior to machining; a modified heat treatment has been introduced to give better long-time, high-temperature ductility, although at some sacrifice in high-temperature strength; and the piping of steam-seal regulators has been modified to minimize the possibility of wet steam thermally stressing the rotor wheels.

The fracture originated at the two holes in the wheel rim through which the notch bucket is attached to the wheel, and an improved notch assembly has been developed in which such pinning is not required. The developments and investigations aimed at producing a turbine rotor steel with greatly improved high-temperature long-time ductility are by no means limited to the change in heat-treating temperatures; the effects of significant changes in alloy composition together with liquid quenching from the austenitizing temperature are also being investigated on full-size turbine rotors. In addition, the effects of vacuum pouring of the rotor ingot are also being investigated on a full-size turbine rotor to determine if this practice, in addition to the improvements in room-temperature properties expected from this innovation, will also produce an improved high-temperature ductility.

In the several months immediately following the Tanners Creek fracture, all duplicate units were thoroughly inspected; in particular, the notch buckets were removed from the first-stage wheels and a direct inspection made of the wheel rims in the vicinity of the notch opening. No signs of any incipient troubles whatsoever were found in these inspections. It should be noted that the No. 1 unit at the Philip Sporn Station of the American Gas and Electric Company system, which unit is identical to the Tanners Creek No. 1 unit, had experienced an overspeed of between 40 per cent and 50 per cent several months prior to the subject fracture, and later inspection of this unit showed no signs of trouble except for the loss of some bucket covers in one of the latter stages and rubbing of the root spill strips on the first-stage (reheat) buckets.

The presence of residual stresses seems to be one of the major contributing causes of this wheel fracture, and, as previously stated, has resulted in the policy of measuring such stresses on all rotor forgings prior to machining. The results of such measurements on a number of roots produced since the Tanners Creek fracture indicate that the residual stresses in the latter were unusually high and in particular are not representative of the results normally obtained with this alloy or its manufacturing practice.

Failure at Ridgeland Station

An extremely complete and interesting report of the causes of the mishap in a 165,000-kw cross-compound steam turbine was presented by **H. D. Emmert** of Allis-Chalmers Manufacturing Co. Shortly before midnight on December 19, 1954, the low-pressure turbine spindle of Unit No. 4 in the Ridgeland Station at Chicago of the Commonwealth Edison Company burst during a routine overspeed-trip test. Immediately following this tragic occurrence, a continuous and intensive investigation of its circumstances and cause was initiated and completed within four months. The paper was prepared to present the story of the investigation and analysis of the accident. From its inception, the primary purpose of the investigation has been to increase the knowledge of the steam-turbine industry so as to minimize the possibility of similar occurrences in the future.

Ridgeland No. 4 is of conventional cross-compound design, with the high-pressure turbine turning at 3600 rpm and the intermediate-pressure and low-pressure turbines in tandem on the 1800-rpm shaft. The unit is rated at 150/165 mw and was placed in commercial service on August 19, 1954. The 1800-rpm low-pressure turbine is of double-flow construction. One end of the shaft is solidly coupled to the low-pressure end of the intermediate-pressure turbine spindle, and the other end is solidly coupled to the generator rotor. The cylinder is of conventional cast-iron construction, with two cross-over pipes connected at the top.

Ridgeland No. 4 was first brought up to speed on July 17, 1954. Five overspeed runs were made on that date during various operational checks. The unit was placed in regular scheduled service on August 19, and there were a total of ten start-ups, including nine overspeed tests, prior to the start-up of December 19. The vibration history of the turbine during this period was excellent. Operation was smoother than average in the opinion of both field engineers and station operators.

Unit 4 was taken off the line the evening of December 17 to clean the boiler. Both shafts were kept on turning gear until the evening of December 19, at which time the turbine was rolled with steam preparatory to being put back on the line. The speed was brought up to 3000 rpm, as measured on the high-speed shaft, in about an hour and a half and the vacuum-trip setting was checked. Following this trip, the speed dropped to about 1500 rpm. The high-pressure shaft governor was then made inoperative and speed was increased until the low-pressure shaft overspeed governor tripped the unit at 7.8 per cent overspeed. The speed dropped to about 3000 rpm at which point the trip tester was placed in position to make the low-pressure overspeed trip inoperative during the anticipated succeeding high-pressure turbine trip. Speed was then again increased and at 3910 rpm, or 1955 rpm on the low-speed shaft, corresponding to 8.6 per cent overspeed, the low-pressure turbine spindle exploded. The accident occurred without warning, there being no noise or rubs or other abnormal indications up to the instant of failure.

Although it was not possible to remove parts and fragments of the turbine from the station for some weeks following the accident, visual surveys of the spindle pieces were made immediately by our engineering and metallurgical staffs. It was found that the main body had burst into four main pieces. One piece was hurled through the air and fell into the basement adjacent to the condenser of Unit 1. Another piece flew in the opposite direction and was eventually located in the station coal pile. The remaining two pieces came to rest in the condenser of Unit 4 and were removed.

A probable sequence of failure can be established with considerable accuracy from the examinations of fragments. While the failure was explosive in nature and occurred completely in only a very small fraction of a second, the sequence of events is believed to be as follows:

1—Initial failure originated at the bore within the main body and progressed in a longitudinal plane both radially and toward the shaft ends, tending to split the

main body into two halves. The actual pin-point of origin cannot be determined positively, but a probable location has been identified as a granular area on one of the major cleavage surfaces adjacent to the bore.

2—Extension of the primary failure into the shaft ends was limited by the clamping effect of the shrunk-on rings. These rings also restrained the two halves of the main body, and extremely high stresses were then set up at the fillet corners. Secondary failures from these corners immediately progressed in an inward direction toward the center of the main body.

3—As cracks from the fillet corners progressed in a direction to free the halves of the main body, strong centrifugal forces in each of these halves almost simultaneously split them into quarters. At the same time the center portion of the material enclosing the bore in the main body fragmented, leaving conical segments attached to each of the spindle extensions. These segments, already split in two by the original primary failure, also quartered with the larger pieces.

4—The quarter-sections of each of the cones, eccentric and overhung and possibly not yet completely free of the main central pieces, tended to break off at the points of restraint under the rings. At some locations these segments broke free; at others, portions remained attached to the shaft extensions.

While the sequence of failure was originally deduced solely from examination of the fragmentation of the Ridgeland shaft, it has since been confirmed with considerable accuracy by bursting tests of $^1/_{15}$-size cast-iron models.

A study of the sequence of failure has indicated that it originated deep in the mass of the main body of the shaft. Metallurgical examinations have confirmed the fact that the metal was notch sensitive and susceptible to brittle failure. Various inspection techniques have shown the presence of an overabundance of cracks in the form of flakes, providing the notches necessary to trigger a sudden and catastrophic failure of the shaft. The only point of uncertainty is the means by which the shaft maintained its integrity as long as it did. It is probable that failure started when one or more of the numerous flakes in the main body near the bore extended slowly and approached the bore surface, a region of high local stress. At this instant, the brittle nature of the material caused this surface crack to widen into a major separation at an extremely high rate of propagation.

It is evident from this investigation that the Ridgeland low-pressure turbine failure is primarily centered around the metallurgy of large forgings. This and other incidents have served to focus much attention on material specifications and on the general procedures for producing and inspecting these large pieces of metal.

The influence of the material in preventing shaft failures is of primary importance. The susceptibility to brittle failure of the standard nickel-molybdenum-vanadium analysis in common use today is of great concern to the industry. Unfortunately available alternate materials at the same strength levels offer little improvement. Materials totally immune to brittle failure, such as austenitic steel or some non-ferrous metals, have been proposed for turbine shafts, but their lower strength levels and other unfavorable characteristics make their use undesirable. The most logical attack on the problem seems to be in a continuing study of the factors influencing notch sensitivity, such as composition, heat treatment, microstructure, and processing.

Much development work within the forging industry will be required so that techniques and controls are established to eliminate all possibility of flakes in large forgings. The allowable hydrogen content in an ingot is probably well under 2 ppm, and ladle metal generally runs 4 ppm or higher. Even partial control of hydrogen requires controlled heats and close attention to tapping and pouring procedures. Hydrogen-free steel could be produced if the steelmaking process was isolated from all sources of hydrogen, but this is very difficult to accomplish in manufacturing large ingots. Most attempts at hydrogen control have been in the direction of removing the gas after it has already been introduced. One of the most promising current developments is the vacuum-casting process, which has received considerable attention in Europe.

An equally important factor in large-forging development is the improvement of inspection methods. The Ridgeland forging was produced about four years ago, and in the intervening period much has been accomplished in this respect. As a matter of policy, all large turbine shafts are bored axially since optical and magnetic-particle inspection of the bore surface gives a good indication of the general quality of the forging. However, some of the more dangerous types of discontinuities may lie away from the bore and hence not be detectable by bore inspection. Ultrasonic inspection has become our most important tool for the interior examination of metal masses, and intensive effort has been put into the development of improved sonic-inspection techniques. Forgings are now searched both radially and longitudinally at various frequencies, and techniques for searching radially outward from the bore are under development. Shear-wave crystals have been brought into use to improve the examination of areas formerly difficult to reach with straight crystals.

Even more important than the development of new sonic-inspection techniques is our continually increasing knowledge enabling better interpretation of test results. Sonic testing is very sensitive, and interpretation requires a considerable amount of background experience. The most common sonic indication is that of inclusions and segregations of inclusions found in nearly all large forgings. It is frequently difficult to distinguish between these harmless types of discontinuities and the more dangerous types of flaws such as flakes or thermal cracks. It is now considered that the determination of pattern and distribution of indications is as important as the measurement of the magnitude of any particular individual indication, and it is in this respect that a growing background of experience and information in interpretation is greatly improving inspection.

Discussion

In the discussion of the paper by **Vernon L. Stone** of Commonwealth Edison Co., it was revealed that independent surveys of the cause of the mishap were made by Battelle Memorial Institute, Sargent & Lundy and Dr. A. E. White, consulting metallurgical engineer. These independent investigations reached the conclusion that the design was conservative and the stresses, even at the fillets, were well within safe limits. The failure has

played an important role in putting new emphasis upon forging techniques and testing methods, and the clear cut results and marked agreement of investigations by both the manufacturer and the consultants have given the industry even more confidence in the safety of using large rotating masses in steam-turbine-generators. Mr. Stone revealed that Ridgeland Unit No. 4 was returned to commercial operation on November 19, 1955, less than eleven months following the tragic occurrence.

Other engineers discussing Mr. Emmert's paper pointed out the desirability for developing more simple inspection method of turbine-generator components for *field* use. Also, during the forging operation, new and more accurate tests must be developed to identify hydrogen flakes, embrittlement and serious segregation of materials in large ingots from which the forgings are made.

A. O. Schaefer of The Midvale Co. expressed the sentiments of many of those present in observing that all can be thankful that the causes of the failure are known and are not in any way so obscure or contradictory as to cloud the results of the several investigations.

Arizona and Cromby Generator Rotor Fractures

Four engineers from the General Electric Co., **C. Schabtach, A. W. Rankin, E. L. Fogleman** and **D. H. Winne,** supplied information on investigations of two large 3600-rpm generator rotors which burst during 1954 while rotating near rated speed. In both cases the fractures were of a brittle nature and occurred suddenly and without warning. The materials were ductile by common standards and of a type widely used in this country for generator rotors. Although the rotors were relatively large—one was of the largest size built thus far for 3600-rpm—all of the many others of the same sizes have operated satisfactorily. The design stresses in relation to the mechanical strength of the materials provide for adequate margins of safety.

The exceptional nature of these accidents, coupled with the great importance of reliability in central station generating apparatus, called for a complete and careful investigation of all features of the design and manufacture and of the characteristics of the materials of the rotors, all of which might clarify the cause of the trouble. This investigation was initiated promptly and is being carried out energetically with all of the resources available.

The investigations presented in the paper have established that these rotors burst because of particular differences between them and others of the same size and design. These investigations have confirmed the soundness of the normal design features and the adequacy of the materials specified, and, with the improved practices which will henceforth eliminate the particular differences which were the major causes of the two bursts discussed here, there is no reason to believe that reliable units of still larger capacity cannot be built in the future. Beyond this, these studies have improved our general knowledge of the behavior of steel in these large rotor masses. This knowledge, coupled with the alloy and steelmaking modifications now being intensively investigated, should result in steels with properties even superior to those of the rotor alloys for which past records of successful operation have been established.

On March 4, 1954, the rotor of a 147,000-kva, 3600-rpm generator being manufactured for the Arizona Public Service Co. burst while being balanced in the factory. The balancing was being done in the "precision balance pit," a below-floor-level trench in which the rotor was driven by a small steam turbine. It had been run intermittently at speeds below 2000 rpm as part of the normal balancing procedure and was being brought slowly up to full speed when it burst suddenly at about 3400 rpm.

The body dimensions of this rotor were 39 inches in diameter by 15 ft long. Several dozen others of the same or larger size are in service. The Arizona rotor, however, was unique in two major respects: First, the number of large indications observed during ultrasonic testing of the rotor forging was greater than in any other forging accepted since sonic testing of rotors was begun in 1947. Second, a series of plugs had been shrunk into the bore of the rotor to increase its magnetic capacity.

After the rotor burst, it was evident from the large number of fragments and examination of the fracture surfaces that the burst occurred in a brittle manner. No single origin of fracture could be found. However, there were numerous flat, circular areas of about $1^1/_4$ in. in diameter on the primary fracture surfaces, noticeably different in color and texture from their surroundings.

On September 27, 1954 the rotor of the 216,000-kva generator at the Cromby Station of the Philadelphia Electric Co. burst while running at 3780 rpm to check the overspeed trip preparatory to putting the machine on the line following a weekend shutdown. The unit had been put in service about three months earlier and had previously satisfactorily undergone two overspeed trip tests to 3950 rpm. It had been started and stopped twenty-one times.

Except for an oil and hydrogen fire which was quickly extinguished and minor damage to the turbine due to vibration plus a sudden forward movement of the rotor, the damage was contained within the casing of the generator. Preliminary observation of the generator following the accident showed that the generator field had burst in about the same manner as the Arizona rotor. Subsequent examination of the broken pieces showed that the main fracture in the rotor passed through a row of holes drilled and tapped into the rotor body to hold studs used to repair damage caused by the breaking of a milling cutter during machining of the coil slots.

The forging which was used for the Cromby rotor is one of the largest employed for 3600-rpm machines. As received from the vendor the forging weighed about 118,000 lbs and was 36 ft long with a main body 43 in. in dia and 20 ft long. Forgings of the same size have been employed in 16 other generators put in service since 1953. All of these have operated satisfactorily.

This forging was produced from an 82-in. octagonal ingot weighing 269,000 lb. An acid open-hearth heat filled the body of the ingot plus three in. of the sinkhead, and a basic electric furnace heat filled the hot top.

It was concluded that the Arizona and Cromby rotor bursts were caused primarily by unusual and severe stress concentractions combined with the characteristics of the materials from which these rotors were made. In the Arizona rotor, these stress concentrations were created by numerous internal cracks in the body of the forging. Although the best methods of nondestructible examination known at the time were used to determine the soundness of the forging, ultrasonic indications in

the body were interpreted as caused by harmless dirt and slag similar to that found in the bore. In the Cromby rotor, these stress concentrations were created by a row of holes drilled and tapped in the rotor body for the attachment of studs used to repair portions of the teeth damaged when milling the coil slots.

Alloy segregation, in string-like regions of above-average alloy content, contributed to the cause of both bursts. The strength and ductility of the metal in these segregations has been found to be low. In the Arizona rotor, the segregations appear to have been the nuclei of the internal cracks formed during manufacture of the forging. In the Cromby rotor, the corner of the stud hole at which the primary fracture originated was in one of these segregation regions. This coincidence seems to explain the bursting of this particular rotor when spin tests of models and the successful operation of other identical rotors indicate that it should not have burst.

The hydrogen content of both rotors caused the ductility of the material, as measured in tensile tests, to be lowered significantly. However, the hydrogen is believed not to have been the cause of the brittle nature and rapid propagation of the fractures throughout the rotors. It may have contributed to the starting of a small crack at the corner of the stud hole in the Cromby rotor, but no evidence of such a small crack, different in character from the rest of the primary fracture, could be found. In the Arizona rotor, the hydrogen may have contributed to the formation of the internal cracks during manufacture of the forging, although the amount of hydrogen present was at the lower end of the range normally associated with hydrogen flaking.

This investigation has led to a better understanding of the relationship between the behavior of steel in massive rotors and its behavior in laboratory tests and of the relationship between its behavior in different kinds of tests, which afford guidance for mechanical design within the limitations of available materials and for the development of better materials. It appears, however, that bursting tests of essentially full-size models or of complete rotors may be necessary to a full understanding of these relationships and to prove the real margins of safety against bursting of such rotors. Accordingly, a facility in which to make such tests is being designed.

Material suitable for rotors and having greater resistance to brittle crack propagation can be obtained by alterations in composition and heat treatment coupled with improved melting practice to improve cleanliness and reduce the effect of nonmetallic inclusions. Accordingly, extensive laboratory studies and full scale trials of such alterations and improvements are being carried out. Successful culmination of these will permit added margins of safety against the unknown and unforeseeable to be built into our machines. In the meantime, use of more stringent ultrasonic acceptance standards, discontinuance of tooth repair with studs, and introduction of improved design, manufacture, and inspection techniques will prevent the recurrence of the conditions responsible for the Arizona and Cromby bursts.

Turbine and Generator Forgings

The materials used for turbine and generator forgings were described, together with precautions taken with respect to soundness and high quality, in a paper entitled "Large Rotor Forgings for Turbines and Generators" by **R. E. Peterson, N. L. Mochel, J. D. Conrad** and **D. W. Gunther** of Westinghouse Electric Corp. Although important progress has been made in recent years, it is recommended that the following directions be pursued: (1) Continue advances in ultrasonic detection and evaluation; (2) strive for lower transition temperature in rotor materials as an added margin of safety; (3) consider starting procedure which assures a bore temperature near that of normal operating conditions when the rotor is brought to speed. This would provide an added margin of safety and might involve a longer starting period for a turbine after a prolonged shut-down, or preheating of a generator rotor. In this connection it should be mentioned that it is our belief, based on all available evidence, that a sound, ductile rotor, free of severe stress concentrations, possesses a large margin of safety.

Some tests of cast iron and steel model rotors were described. Tests of model cast iron rotors gave results in agreement with a theory regarding a mode and sequence of failure at Ridgeland. The steel model did not fail until the mean stress reached the tensile strength. It should be noted that the mean stress in a typical turbine generator is only about $^1/_4$ of the tensile strength at 20 per cent overspeed. Differences, other than defects, which can occur in large rotors as compared to model rotors, and which might conceivably affect the strength have been studied and should continue to receive careful consideration.

An instance was cited wherein a 100,000-kw turbine generator was accidentally overspeeded 50 per cent without failure; at this overspeed the mean stress was about $^1/_2$ of the tensile strength.

The fatigue problem was discussed and the role of careful alignment emphasized. Since starting and stopping may be regarded as cycling, this was discussed as a fatigue problem and the indications based on calculations were that only a very severe defect, unfavorably oriented, would be expected to behave as a source of a fatigue crack. Such defects are quite rare and readily detected by modern methods: under no circumstance, as previously indicated, would defects of this type be acceptable.

All aspects of turbine and generator rotors—material, inspection methods, design—are being continuously reviewed, to assure that reliable rotors will be produced to satisfy the growing requirements of the electric power industry.

In a paper entitled "Acceptance Guides for Ultrasonic Inspection of Large Rotor Forgings," **A. W. Rankin** and **C. D. Moriarty** of General Electric Co. discussed interpretation techniques, nomenclature for ultrasonic inspection, formation and calibration of inspection guides and reviewed records of 1500 rotor forgings. The acceptance guides are based on design and manufacturing experience with turbine and generator rotor forgings in the weight range of approximately 20,000 to 150,000 lbs. These guides recognize fundamentally the extreme difficulty of producing forgings in this weight range completely clear of ultrasonic reflections, and they furnish reasonable and conservative assurance against the acceptance of forgings containing injurious defects. They furnish an outer line below which cracked forgings have not been encountered, an inner line which is well within the outer

line, and a trepanning policy for the evaluation of forgings whose number/magnitude lines are outside either the inner or outer lines. Accordingly, these acceptance guides furnish a means of guarding against the acceptance of forgings with injurious defects without causing the unwarranted rejection of harmless inclusions.

It should be noted that these acceptance guides are suggested only for application to the specific weight range in which they have been evaluated, and in this range no attempt is made to distinguish between individual weights and diameters. Specifically, these guides are used directly for either a 20,000 or a 150,000-lb forging. Although the defect reflection magnitude has no direct relation to the forging weight or diameter, being based solely on the bore reflection, there is some evidence that the number of defects increases with both forging weight and diameter. Therefore, it is possible that using the number of indications as a criterion penalizes the larger forgings, and it might be more logical to use instead the number of indications per unit volume. Since other qualifications of equal validity can also be considered, as for instance the axial and radial distribution of defects within a given unit volume or even the operating stress levels, it appears more conservative to consider primarily the defect magnitude and number of defects alone. In particular, it should be noted that the penalty of this simplification is only that further evaluation, in the form of trepanning, may be more frequent than necessary on the larger forgings, but in view of the recognized difficulty of producing the larger forgings to the high quality standards desired by both the vendor and user, the possible additional trepanning to ensure freedom from injurious defects is not warranted.

It is fully appreciated that the available data for establishing these acceptance guides are rather limited, although the authors believe that these are the best and most extended data available. Further trepanning will be done in the future on an almost continuous basis, and the positions of the inner and outer lines will be revised whenever the results of the trepanning indicate that such revision is necessary. The authors' company believes, however, that this publication of current acceptance guides together with the limitations of the data on which such guides have been based is to the best interests of the power-generation industry. In the future it is planned to publish in a similar fashion any modifications of the inner and outer lines if trepanning should show that such modification is necessary.

Brittle Failure Task Group

The last paper in the symposium, "The Work of the Task Group on Brittle Failure of Steel Forgings" was presented by **A. O. Schaefer** of The Midvale Co. on behalf of ASTM Sub-Committee VI of Committee A-I on steel products. This task force comprises representatives of eight companies—three manufacturers of electrical equipment, five manufacturers of large forgings for turbines and generators. This represents all of the makers and users of large forgings of this type in the United States. The Task Force has met monthly since it was formed. Partial meetings were held in Europe during the recent World Metals Congress.

It began its work by reviewing the failures discussed at this meeting. These were described in detail, and the comments of the Task Force guided the testing.

Fourth Annual Conference on Atomic Energy in Industry

UNDER the auspices of the National Industrial Conference Board a highly successful conference on atomic energy was held at the Waldorf Astoria Hotel in New York City on October 26–28. More than two thousand business executives, engineers and scientists from countries on both sides of the Iron Curtain were present for the meeting which had as its theme "International Cooperation for Betterment of Mankind." Among the subjects discussed were nuclear power costs, methods of building and operating a nuclear plant, an evaluation of how the amended atomic energy act is working, and problems of selling in the foreign market. In conjunction with the conference, the Conference Board announced the formation of an industrial atomic energy department which is to be directed by R. M. Ballinger. This department will continue the program of annual atomic energy conferences and management training courses and will also undertake research in the economic and management problems relating to the industrial applications of atomic energy.

Controlled Thermonuclear Reactions

Although controlled thermonuclear reactions have been subjected to wide speculation since the subject was discussed at the Geneva Atomic Energy Conference, it remained for **Dr. Henry D. Smyth** of Princeton University, former U. S. Atomic Energy Commissioner, to present an extended unclassified discussion of the subject before a large lay and scientific audience. Tracing the history of modern physics, Dr. Smyth pointed out that by 1938 enough had been learned about the nuclei of atoms and the forces which hold them together to justify speculation about the possibility of nuclear reactions as a source of energy. In fact, it had been suggested that the heat of the stars, including the sun, was the result of nuclear reactions, and Dr. H. A. Bethe had actually proposed the detailed series of nuclear reactions which might be responsible for the release of this energy. Many laboratory experiments had been performed, which resulted in the transformation of one element into another. Most of these experiments, and the discussions that centered around them were concerned with nuclear reactions in the light elements, so that one can fairly say that fusion reactions have been known in principle a good deal longer than uranium fission. The principles that were basic to the discussion in 1938 remain largely unaltered. We are still attempting to achieve fusion reactions on a large scale by surmounting difficulties which were already foreseen in 1938.

Required Temperature

There is no trick way to produce fusion nuclear reactions, Dr. Smyth stated. In fusion nothing plays the role played by the neutron in fission. The only way we see to do it, is to get large numbers of the necessary nuclei going at such high speeds that they will collide with each other and react. This means raising appreciable masses of material—for example deuterium—to temperatures comparable with the temperatures inside the sun, temperatures that have been achieved on the earth, so far as we know, only in

atomic bombs. Furthermore, once these temperatures are produced, and the fusion reaction occurs, it must be under control to such a degree that we are actually able to get useful energy from it.

One way to contain the reacting substance is to make use of forces which, like gravitation, act at a distance on material bodies under certain conditions. Atoms are normally neutral with enough negatively charged electrons in their outer structures to neutralize the positive charges on the nuclei. But the forces that hold these electrons to the nuclei are trivial compared to the forces holding the nuclei together. As the violence of collisions between atoms of a gas rises with rising temperature, the outer electrons are knocked off at temperatures much lower than are needed to produce nuclear reactions. Consequently, when we talk about confining a gas at a temperature of a million degrees, we are talking about confining an assemblage of charged particles differing substantially in its properties from the neutral molecules of a gas at ordinary temperatures.

Astrophysicists are familiar with this kind of gas at the high temperatures in stars. Earth-bound physicists are familiar with this kind of gas at moderate temperatures in electrical discharge tubes of various kinds. They know that such a plasma, as it is called, responds to the action of electric and magnetic fields. They know, too, that it is possible to feed electric energy into such gas, thereby raising its temperature.

It may be possible to heat a gas, for example, deuterium, electromagnetically to the point where thermonuclear reactions set in and at the same time to confine this reacting gas by some arrangement of electric and magnetic fields. If this proves to be feasible, Dr. Smyth added, there still remains the question of recovering the energy generated by the thermonuclear reactions.

If energy can be recovered, there is still the question as to whether an operating device will consume more energy than it generates, a characteristic of all laboratory devices in this field. If the thermonuclear reaction is achieved, if the reacting gas can be confined, if the energy can be recovered and if the energy balance is favorable, there still remains the question how much the energy will cost.

Nuclear Transportation

In a paper entitled "The Outlook for Nuclear Transportation" **Lyle B. Borst,** chairman of the Department of Physics, New York University, stated that nuclear transportation represents the application of small package power plants to restricted and specialized use. In the field of military transportation cost considerations become secondary and performance primary. In civil applications nuclear energy is competing with an expensive portable restricted power source so that an economic profit could be expected in the near future.

As compared to central station power plants, the transportation industry would require the production of

a number of identical units to be fabricated under favorable conditions for mass production. In operation the units could return to central fuel and maintenance bases.

Submarine transportation is a reality and is justified because for the first time we have a submersible ship capable of indefinite cruising submerged. Previous submarines were limited in the time submerged by stringent requirements on energy storage either in electric batteries or in fuels and oxidants. Weight, space and power specifications are met without excessive difficulty. Particular attention must be given to possible leakage of radioactive liquids and gases from the reactor because the crew must live within a sealed container for long periods. For future application one might think of merchant submarines of large cargo capacity which could travel without concern for weather and wave conditions. Surface vessels, merchant or military, are achievable now, provided there is an economic or performance advantage. Safe designs for such power plants have been developed.

Nuclear Aircraft

The nuclear aircraft places the most stringent requirements upon the design engineer to minimize weight and safeguard the crew, according to Prof. Borst. The reactor power plant, exclusive of shield, can be built within the size and weight specifications of an aircraft without difficulty. Application to jet engines would be a probability using either an open cycle air system or a closed cycle liquid metal system. When shielded, the power plant could easily become excessive in weight. Remote location of the crew will reduce shielding requirements.

In the field of surface land transportation the railroad appears to be the only technically feasible application. Here stringent dimensional limitations are imposed. Special duty reactors can be devised which will meet the power requirements, leaving sufficient room for adequate radiation shielding. The weight of the assembly falls within the range of accepted railroad practice although near the upper limit. The economics of this application are available for review. Accepting the Atomic Energy Commission price for uranium, the railroad locomotive competes with present diesel practices under favorable conditions.

Insurance Problems

Arvin E. Upton, partner of LeBoeuf, Lamb and Leiby, in a paper entitled "Reactor Operators and In-

surance Legal Problems" stated that there is a need to place peripheral problems related to private atomic energy activities in their conventional context and not stress excessively their uniqueness. This is true of insurance and liability problems.

What are the questions posed to itself by the management of a company planning to build and operate a reactor?

The first question is how safe is the reactor? AEC experience and expert opinion indicates it is quite safe but it will not be foolproof and the catastrophe potential is enormous.

The second question is what are possible kinds of loss and liability? These would comprise plant damage, plant loss of use, injury to employees, third party liability and liability to AEC for loss of special nuclear material and from a licensee's obligation to indemnify AEC. Third party liability is the most serious element. Potential liability under indemnification obligation is probably slight but responsibility for loss of material may result in very large financial liability. Third party liability may be based on legal doctrine related to ultra-hazardous activities and liability may result even though no fault.

The third question is what are company's resources to handle these losses and liabilities? A large company may by itself or in cooperation with others act as self insurer to some extent. Existing liability insurance policies may cover situation but they have monetary limits. Existing property policies probably do not apply to atomic incidents. To some extent the company operating a reactor might be able to pass back liability to the manufacturer under product liability doctrine.

The fourth question is how to secure additional protection needed. It must come either from private insurance companies or from the Government.

Role of Insurance Companies

Private insurance companies are making genuine efforts to come to grips with the problem, both collectively and in individual policies already written, according to Mr. Upton. In negotiation of special coverage particular attention must be given to the questions of (1) loss of use in circumstances where effects of radiation and duration of effects are uncertain, and (2) when death may eventuate from radiation long after incident involved. Insurance industry cannot come to conclusion until atomic industry gives firm estimates on what is required. Even then, insurance industry must accumulate experience before extensive coverage at reasonable rates can be expected. In any case, catastrophe potential is probably too great for private insurance industry to handle.

The eventual question therefore is as to the appropriate participation of the Government. No Government participation should be considered until industry comes up with constructive planning going as far as possible. Government participation should be justified as analogous to research assistance during experimental period. Government participation might take the form of direct indemnification, Government reinsurance or Government excess coverage insurance. Any legislation should provide for review of situation after 10 years and if possible Government role should be limited to hazards connected with contamination by radioactivity, since these are the hazards containing most of the unknown factors.

Statutory limitation of liability is rejected as impracticable if incorporated in state legislation and as of doubtful constitutionality if incorporated in Federal legislation.

There is no dramatic and simple solution of the problem. There is time left to work for solutions. There is no indication that reactor develop-

ment thus far has been held up by failure to solve insurance problem. Matters will be quite different, however, in three or four years when the first power reactors are ready to go into operation. The insurance industry must work out solutions to the best of its ability by that time. If this is not enough and Government participation is needed, it should be requested without hesitation and welcomed.

Nuclear Fuels

Despite many attractive features of liquid nuclear fuels for reactor use, **Bernard Kopelman** of the Atomic Energy Division of Sylvania Electric Products Inc. stated that solid fuels remain far ahead in the race. This can be attributed to several reasons. First, the majority of efforts for the past fifteen years have been applied to solid fuels, and nothing can fully replace the experience of long-term operation. Second, corrosion and mass transfer of the containers, piping, valves, etc., by the hot moving fluid is a problem of the greatest magnitude and not yet fully resolved.

Solid fuel elements have a limited life because of distortion by radiation damage. Liquid fuels limit the life of a reactor by corrosion. It is easier to replace the solid fuel elements than to replace the container and piping of the reactor which had been liquid fueled. As a matter of fact, the corrosion problem must be solved, or liquid fueled reactors will not be used at all.

A different point of view was presented by **John J. Grebe,** director of nuclear research and development of The Dow Chemical Company. He stated that the need to replace the primary heat transfer surface of the reactor every time the solid fuel has been spent by the consumption of a few per cent of the atoms of its structure would be like having a steam boiler which must be dissolved with acid, repurified, realloyed, refabricated and reinstalled once each year. While this might be economical for many special uses, such as on a submarine, it could not possibly become commercial on a large scale.

The specific advantages of mobile fuel reactors lie in (1) continuous fuel processing, with its lower costs, particularly because there are no expensive fuel elements to fabricate, higher conversion ratio possibilities, and the added return from the radiation from very fresh fission products, (2) higher temperature for maximum efficiency energy conversion and (3) safety, which includes the inherent self-regulation of fluid fuels and the need

for only the slightest excess reactivity in the core.

Dow Chemical Co. have decided to proceed with the actual planning and engineering of such a reactor system. As soon as preliminary design and testing can be done, the evaluation proved satisfactory, and the necessary licenses and clearances obtained, they intend to build such a unit at one of their locations.

Nuclear Reactor Operating Problems

Marvin Fox, chairman of the Reactor Department of Brookhaven National Laboratory, stated that the operation of a nuclear reactor, whether it be for the production of power, by-product material, or in the support of research, is no different than the operation of the more familiar industrial chemical plant or power station. They all depend for smooth performance on just two elements of good management: (1) a well-engineered and reliable system; and, (2) a thoroughly trained, capable and loyal operating organization.

The best way to set up an operation staff is to have a large staff of versatile supervisors and operators capable of doing the day-to-day manipulation of the control system, the fuel handling, the by-product production activities, and the record keeping. As long as operators' licenses are required it is quite likely that this will not be possible because operators will be people who manipulate controls and perhaps do nothing else, especially if a union of operators is formed. This can be expected. If this is so, the operations staff will necessarily be specialized rather than versatile and will constitute a heavier overhead. If, for instance, a special crew is required for the fuel handling it might be difficult to keep them busy unless they also do things like by-product activities and record keeping.

Each crew responsible for the operation of the reactor might consist of a supervisor and several operators if the reactor is at all complex and large. If it is a shift operation, there will be the usual features associated with any type of shift operation. There are well-established patterns for all of this. The supervisor should be a man with an engineering degree and should have some experience in plant operations of one sort of another. He should also have had a least one year's training on a reactor operations staff and understand thoroughly the fundamental principles of all nuclear reactors. He must be thoroughly familiar with all the characteristics of the reactor of which he has charge. The head of operations will have to erect minimum standards which must

be met before a supervisor is put in charge of the reactor. The operators, as the law stands now, will also have to meet certain standards and tests.

Necessary Records

Detailed records on all the pertinent features of the operations are essential, according to Mr. Fox. For one thing, such records will undoubtedly be useful in determining the long-term changes in the behavior of the reactor and in some of the components. This is especially true of systems on which there is very little operating experience. The records are most essential to the accountability aspects of the licenses issued by the AEC to control the transfer and use of source and special nuclear materials. This function is a direct responsibility of the head of operations and he may require a substantial staff of people to look after it.

The size of this staff will depend upon some of the conditions of the license. If the license incorporates a requirement for making assays or analytical determinations of the constituency of the source and special nuclear materials, the staff could be quite sizable and include some top level chemists or physicists. If, on the other hand, the accountability requirements can be satisfied by paper calculations based upon the irradiation history of the materials, the staff could be small and consist of a part-time reactor physicist for advice, an accountant, and a few clerks. This manner of accountability depends upon having very good history on the movement of the source and special nuclear materials into and out of the reactor, and a good knowledge of the neutron flux pattern and operating characteristics of the reactor core. This, in turn, means that the services of some reactor physicists will be needed in connection with the initial startup of the reactor and all through as much as the first year of the operations. In some cases, these services will be provided by the organizations who are designing, building and putting the nuclear plants into operation. Even so, it is wise for a head of operations to have a good reactor physicist as a full-time employee on his staff on a permanent basis.

Russian Heavy Water Reactor

In a talk by **V. V. Vladimirsky** of the USSR Academy of Sciences, the question was posed whether electric power stations with such low thermal efficiency, as currently achieved in nuclear power plants, can be sufficiently attractive economically to

build them. For an ordinary thermal power station a negative answer is inescapable. There is a reciprocal relationship between the fuel cost per kilowatt-hour and the thermal efficiency of an electrical power station. Because of the large fuel costs, characteristic of thermal electrical stations most thermal electric power plants with a low thermal efficiency are unprofitable.

The situation is different for atomic electric power stations. The construction costs of such electric stations and their current operating expenses are higher than those for thermal electric stations. Therefore, atomic electrical stations can compete successfully with coal stations only in case that the fuel cost per kilowatt-hour for atomic electrical power stations is not great. And if it is really not great, then it is profitable within limits, to lower the thermal efficiency and thus attain the maximum power for given capital investment and operating expenses.

What must we do, Mr. Vladimirsky asked, in order to lower as much as possible the fuel cost per kilowatt-hour in an atomic electric power station?

In the ideal case of reactors working with a multiplication coefficient of fissionable materials greater than one, the fuel cost per kwhr can be diminished practically to zero. For ordinary reactors, in order to obtain a low fuel cost per kwhr, one must use as a nuclear fuel only natural uranium without enrichment and have a deep burn-out of uranium 235. This is the very thing that is obtained more easily in reactors using heavy water moderators.

Radioactive Wastes

Walton A Rodger of Argonne National Laboratory discussed the past, present and future of radioactive waste handling. There are three solutions which represent three separate philosophies of waste disposal which might be called: (1) dispersal, (2) controlled containment, (3) partially controlled containment.

Disposal by dispersal relies on the adequacy of mixing of the wastes with large volumes of water or air. Sufficient diluent must be available to bring the concentration of radioactivity below maximum tolerances.

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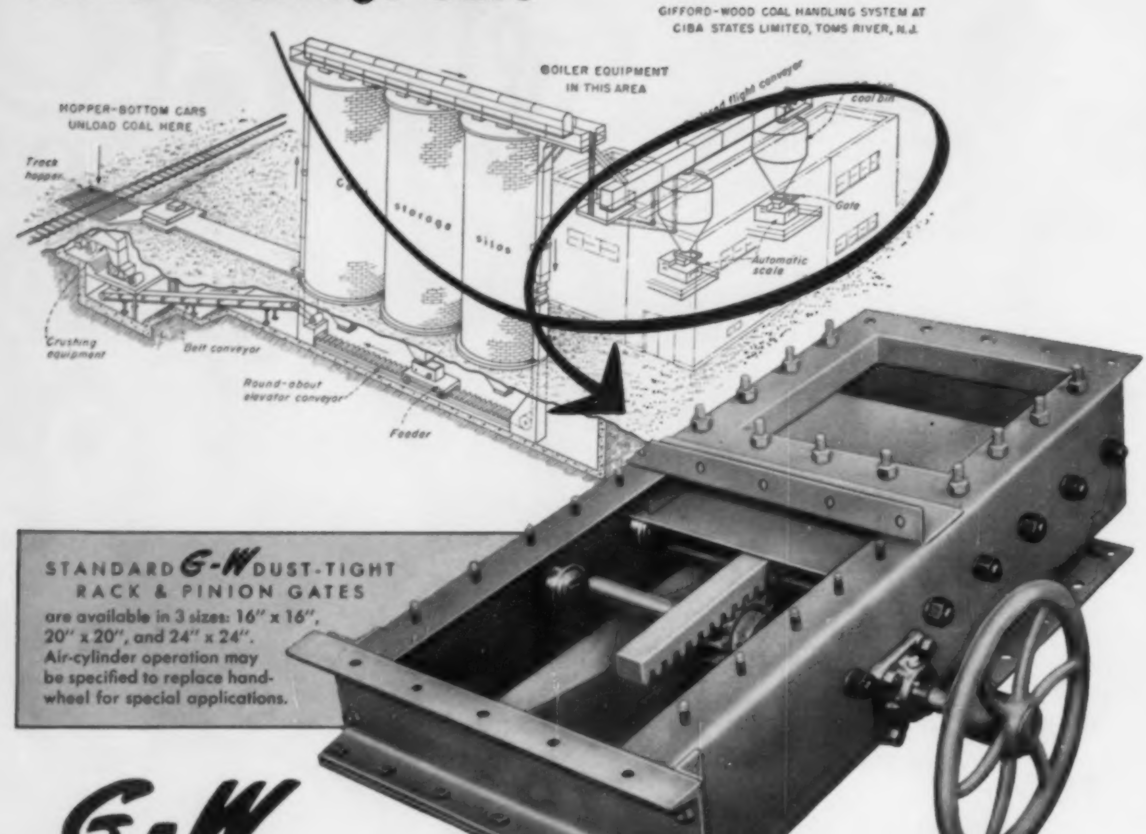

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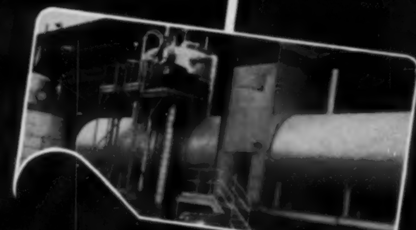

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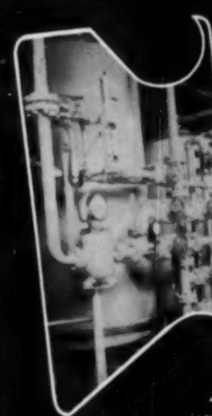

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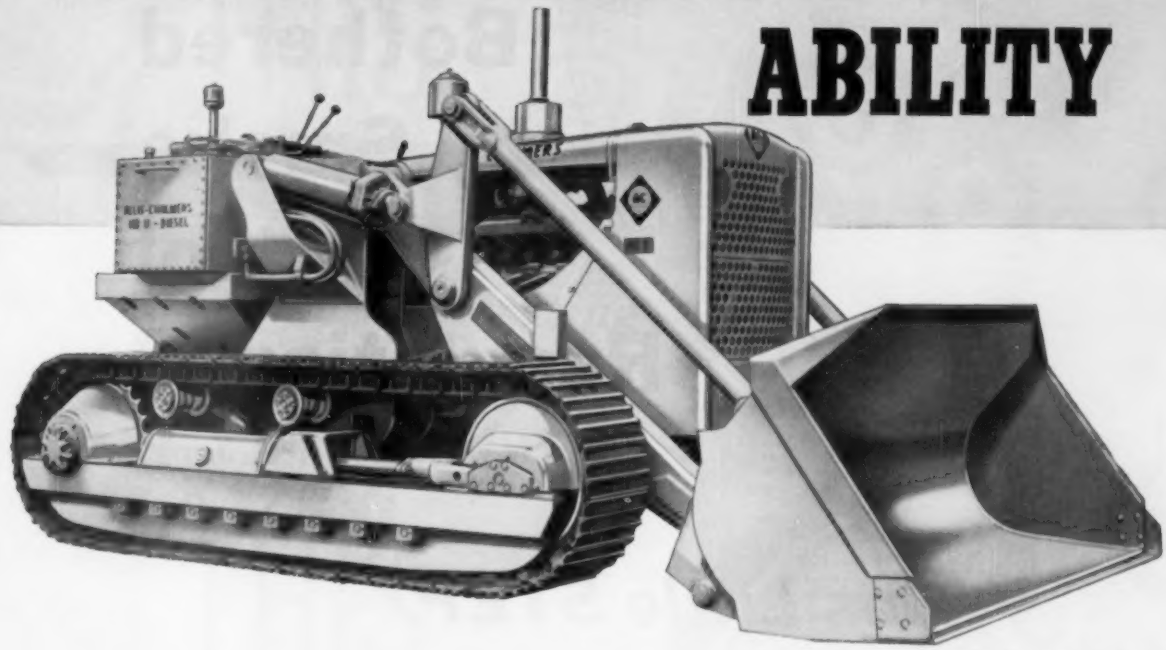
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(Continued on page 83)

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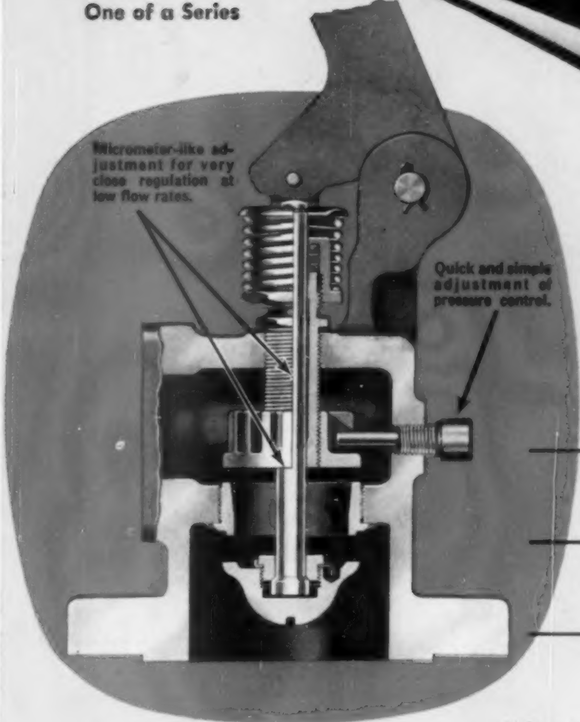

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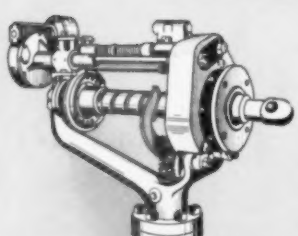

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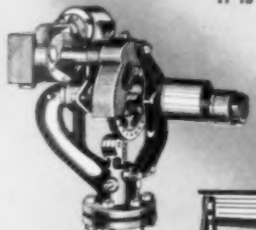

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J. Charles Allen
Chief Engineer, Atlas Powder Company

that Shaw was chosen to fabricate and install the extensive piping for the air-conditioning, the heating, the swimming pool. Shaw's reputation for painstaking planning, skillful fabrication, and dependable installation is world-wide . . . and well-earned. Whatever your piping requirements, look to Shaw to fulfill them—carefully, reliably, economically.

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